

**Understanding the needs of institutions  
for the development of ‘Decision Aids’  
for water resource management**

Learning from the Ruaha basin, Tanzania

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To my fathers

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# Abstract

Today in Africa, water resources must be managed in an integrated manner. This is the message put forward by donors and governments in the last decades. Under Integrated Water Resource Management (IWRM), water managers are requested to recognise the value of water as a social and economic development factor without threatening natural ecosystems and to take decisions with full public consultation. Much effort has gone into developing computer-based Decision Aids (DAs) with the aim to support agencies in implementing IWRM. But their design is challenging and there are still few examples of practical applications.

The present thesis assessed the development and application of a DA model as a tool for water resources management in Africa, through a case study in the Upper Great Ruaha River Catchment, Tanzania. DA's ability to fit IWRM's requirements was examined and software engineering approaches were used with the aim to contribute to DA development sciences. Methods combined end-user participatory appraisal with the development of a DA in an iterative fashion and the testing of two successive versions.

Results show that water managers needed a DA which could help narrowing down the knowledge gap that exists between water availability on the one hand, and water use and allocation on the other hand. This key result justified to streamline research on an "Exploratory DA" (user-oriented), as opposed to a "Research DA". Exploratory DAs were found to enable users to explore potential solutions and increase their understanding of the water resource management system. Software engineering methods were useful in adapting to users' demand. Yet, exploratory DAs are not management tools in the sense of performance improvement, but rather "companion tools" aiming at improving the understanding of users before assisting them to take informed decisions. Unless this is achieved, results show that African water resources are at risk.



# Acronyms and abbreviations

DA	Decision Aid
DSS	Decision Support System
FAO	Food and Agriculture Organisation of the United Nations
GIS	Geographic Information System
GWP	Global Water Partnership
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
NGO	Non Governmental Organisation
RBMSIIP	River Basin Management and Smallholder Irrigation Improvement Project
RBWO	Rufiji Basin Water Office
RIPARWIN	Raising Irrigation Productivity and Releasing Water for Intersectoral Needs
RNP	Ruaha National Park
RUBDA	Ruaha Basin Decision Aid
SMUWC	Sustainable Management of the Usangu Wetland and its Catchment project
SUA	Sokoine University of Agriculture
SWRMG	Soil and Water Resources Management Group
UBM	Usangu basin Model
UGRRC	Upper Great Ruaha River Catchment
UML	Unified Modelling Language
UN	United Nations
UNCED	United Nations Conference on Environment and Development
WRM	Water Resources Management
WUA	Water Users' Association

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# Chapter 1 - Introduction

The present work intends to contribute to solving the crisis linked to dwindling water resources in Sub-Saharan Africa and the fact that this mainly affects poor people. Against this background, the first hypothesis discussed is that there is a gap between the operational reality faced by water managers and users on the one hand and the concepts used to justify approaches towards integrated water management on the other hand. Secondly, it is questioned whether “management tools” (i.e. models and softwares) developed in the international scientific context, and guided by Integrated Water Resource Management (IWRM) concepts, do actually match the operational reality of water users and managers.

Specifically, the following point will be addressed: (1) assessment of the demands and constraints for water resource management, (2) evaluation of the operational context influencing the development of models, (3) assessment of existing model development methods.

In order to make sure that collected information and data serve towards the production of pragmatic results, are useful to both researchers and practitioners and improve our understanding of both water management and of the needs of water catchment users, emphasis has been put on the following issues: (1) the role of end-user engagement in model design, (2) the incorporation of approaches from software engineering methods, (3) the actual conditions of model design and development, (4) iterative research approaches aiming at securing productive feedback from users and other stakeholders.

## **1.1. Improving water management, a solution to the water crisis in sub-Saharan Africa**

Today, about 2.8 billion people worldwide live in river basins facing water scarcity and all sub-Saharan Africa countries face water scarcity (DFID, 2008; Molle et al., 2007). This water scarcity is either the result of the limited human, institutional and

financial capital (economic water scarcity) or the result of a development of water resources that has exceeded the sustainable limits (physical water scarcity). In much of sub-Saharan Africa it is economic water scarcity that prevails (Molle et al., 2007). This implies that, apart from local and specific areas (not necessarily small areas), the water crisis engendered by water scarcity can be solved by improving the management of water resources more than by developing more infrastructure (Molle et al., 2007; CME, 2000; GWP, 1999).

Since the 1990s, investments in water infrastructure decreased significantly and efforts focused instead on improving water management by emphasizing demand management, rationalized water allocation, institutions and capacity building, as well as market tools for promoting more efficient use and operation of existing water supplies. During this period a global consensus emerged to promote a more comprehensive approach to water management, called Integrated Water Resource Management (IWRM) that was intended to move toward sustainable basin management.

## **1.2. Integrated Water Resource Management (IWRM): A concept guiding the interventions of donors and governments**

The four principles that form the basis of IWRM were defined in 1992 during the International Conference on Water and the Environment in Dublin (The Dublin Statement, 1992). These four principles (further discussed in section 2.1.1) are:

- “Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment.”
- “Water development and management should be based on a participatory approach, involving users, planners and policymakers at all levels.”
- “Women play a central part in the provision, management and safeguarding of water.”
- “Water has an economic value in all its competing uses and should be recognised as an economic good.” (The Dublin Statement, 1992)



It was confirmed during the Johannesburg World Summit on Sustainable Development (2002) that these principles were fundamental to reach the Millennium Development Goals. World leaders from 193 countries then committed themselves to preparing national IWRM and water efficiency plans by 2005. IWRM principles were adopted by most donors and included in their intervention strategies (e.g. World Bank, 1993; African Development Bank, 1999; FAO, 1997) and shaped most of the interventions and reforms held in the water sector in sub-Saharan Africa during the late 1990s and the beginning of the 2000s. Thus, in 2005, three quarters of African countries had partially or fully developed IWRM national strategies and included the principles of IWRM in their water related policy documents (GWP, 2006). Despite the concerns and debates that had been growing among the research community and development professionals regarding the applicability, especially in developing countries, of the IWRM concept (Biswas, 2004; Lankford et al., 2005), IWRM had become the mainstream approach to water management. From the late 1990s to the mid 2000s, IWRM was guiding the intervention of donors and governments in sub-Saharan Africa. IWRM thus appears as a renewed approach to water management, clearly different to conventional Water Resource Management (WRM).

### **1.3. The management of water resources under assistance**

Many authors point out the inadequate capacity of water managers (Blagbrough, 2001; Rosensweig, 2001; Lockwood, 2002) that contributes to poor resource allocation and management. These authors posit that managers lack technical, managerial and conflict resolution capacity as well as supportive policies and legislation. Such capacity constraints, coupled with institutional fragmentation, corruption and poor availability of information are also often cited as hampering effective water resources management in Africa (UNEP, 2005). It is important to combine such analyses with the financial context of African countries. Most sub-Saharan African countries are highly dependent on foreign aid and have very low internal funds for investment in the physical and human resource capital required for water resources management. When justifying the need for a new water policy to replace its 2001 water policy, DFID<sup>1</sup> (2008) highlighted that the investments of the

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<sup>1</sup> DFID is the UK Department for International Development.

private sector in the water sector have been lower than expected and that the capacity of local communities to manage and maintain their own systems using user fees has been overestimated. The lack of internal financial capacity to maintain and operate the water management bodies in sub-Saharan countries reinforces their dependency on external funds. As a result, donors are in a position where they have to finance not only the creation of new institutions but their functioning as well. The fact that IWRM was guiding the intervention of donors, and the important role endorsed by these donors that support financially and technically (through cooperation and development project) the authorities involved in the management of water, explains partly the uptake of IWRM (at least in their discourse) by governments and water managers. One of the instruments promoted by IWRM for its implementation is the use of integrated computer based scenario simulation models such as Decision Aid (DA) tools.

#### **1.4. Decision Aids for water resource management perceived as a solution**

*“There is a growing realization among policy makers and scientists that ecological, social-economic and physical aspects of water management cannot be dealt with separately. This has led to a growing number of tools to support the decision-making process in water management dealing with the water system in an integrated way.” (De Kok, 2003:1).*

The need for DA tools to enable water managers to implement IWRM principles at catchment level by integrating knowledge on hydrology, socio-economics and environment has been largely taken up by the international scientific community, as well as by multilateral development banks such as the World Bank (1993), the Asian and the African Development Banks (1999), UN agencies (FAO, 1997), the European Commission and other donors. In 2008, DFID developed a new water policy (DFID, 2008) in which it is stated that water resources management will be improved by supporting efforts to gather and analyse information on water use and availability, allowing better forecasting and more efficient allocation of resources.

Despite the efforts made during the last decades to develop DAs for WRM, there are very few examples of practical applications of DAs (De Kok, 2003).

### **1.5. Developing a functional DA for WRM: a challenging task**

There have been numerous attempts to identify the causes of the non-use of models in general and DAs in particular. Some of the causes identified, such as the limited use of DAs by policy makers and managers, are linked to the modelling, the programming choices made and the easiness to use or the acceptance of the DA by end-users). Although there are a large number of different causes pointed out, there is common agreement that the lack of user participation during the development process is a critical factor (Welp, 2001; Mysiak, 2005). To determine the causes of acceptance, developers have tried to evaluate DAs, their use and their ability to successfully support decision makers (Brooksbank, 2001; Finlay and Wilson, 1997; Harrison and Pelletier, 2001; Wyatt and Smith, 2000; Zapatero, 1996). Early involvement of users is part of the effort undertaken towards increasing the relevance of DAs for policy-makers and managers. The involvement of users allows a better understanding of their requirements and expectations (Welp, 2001; Mysiak, 2005).

Modellers and scientists from natural sciences backgrounds involved in developing DAs are focused on the modelling of natural systems. Software developers are focused on the engineering role of software and have therefore generated a range of tools and methods to capture the requirements of users. Although the two sciences have been described separately, there have been attempts to learn from the other discipline. This complementarity between disciplines appears to be crucial for the development of functional DAs.

### **1.6. Key issues in the development of DAs**

Decision Aids have been in development for about two decades. Practical lessons have been learnt and knowledge generated to improve the development of these tools (Malézieux et al., 2001). A key lesson has been that it is necessary to include early,

intensive and on-going prolonged involvement of users during the design and development of DAs.

I argue that it is also necessary for water resource management DAs be more user-centred than model-centred. This implies that DAs must not be developed for the use of scientists only and based solely on the modelling of concepts, but should be focused on answering the needs of managers. I propose that one way of developing such DAs is to apply methods derived from project management and software engineering. Such methods have proven useful in so far as they provide a rigorous and rather objective software building approach for software developers who often face topics they do not know well (e.g. hydrology for modellers in water management).

The context of IWRM in sub-Saharan Africa is important to this study. Therefore use of project management and software engineering approaches need to be adapted to the local context. As stated by Malézieux et al. (2001), most researchers and software developers consider the users of DAs to be scientists searching for the optimised use of natural resources. This assumption presents a serious advantage when it comes to the analysis of the decision processes and when designing DAs because it limits drastically the number of possible choices and strategies available to users. Tools developed using this assumption therefore tend to an optimisation and an automation of decision making processes which may not be appropriate for WRM in sub-Saharan Africa. Chapter 3 highlights the lack of financial, technical and human resources and also of available data and quality of control, combined with a pluralism of norms (formal and informal) that rules the management of resources and does not put managers in a position that allows them to search for an optimisation of natural resources use.

This thesis embraces De Kok's (2003) call for more end-user participation and project management as key success factors in the development of DAs. This is supported with the recommendations made by many authors such as Malézieux et al. (2001), to take into account the environment in which the DA will eventually be used during the design and development phase. This is necessary in order to ensure DAs

are fit for purpose and accepted by users. A key objective of this present work is to test the development of a DA within the environment in which it will be used.

### **1.7. Water resource management DAs in practice: Research questions**

The objective of this research is to assess the development and application of a Decision Aid (DA) tool for water resource management in sub-Saharan Africa, with particular emphasis on the understanding of the needs of end-users and their engagement in the DA design. The research also considers the potential to incorporate approaches from software engineering to water resource management DAs. The approach and insights gained rests on a case study: The design and the development of a DA for the management of water resources in the Upper Great Ruaha River Catchment in Tanzania. The design and development of this DA, called the Ruaha Basin decision Aid (RUBDA), was achieved as part of a DFID research project spanning a period of approximately five years. It was conducted in an iterative manner, using different methods of end-user participation, as well as different DA development methodologies which led to the development of various versions of RUBDA.

The aim of the research is to improve understanding of both water management and of the needs of water catchment users. The research also aims to contribute to DA development sciences and to be useful to both researchers and practitioners. The methodological approach selected is a form of action research applied to the development of a practical tool for decision-making in a specific context: water resource management in Tanzania.

#### **Action research**

Action research is an established approach to research that appeared in the 1950s and was mainly used in social and medical sciences. It has been applied to Information Sciences since 1985 when Wood-Harper (1985) introduced it as a research methodology to the Information Sciences community. Baskerville (1998:1) posits

that “the discipline of Information Systems seems to be a very appropriate field for the use of action research methods”. Although Baskerville (1998) considers Information Systems in their broader sense, he includes the design and development of computer-based information systems (to which DA belongs) as one of the possible primary goals of what he defines as Information System action research. Baskerville (1999) proposes an adaptation of the definition of action research proposed by Hult and Lennung (1980) to posit the four major characteristics of Information System action research:

1. “Action research aims at an increased understanding of an immediate social situation, with emphasis on the complex and the multivariate nature of this social setting in the Information system
2. Action research simultaneously assists in practical problem solving and expands scientific knowledge. This goal extends into two important process characteristics: First, there are highly interpretive assumptions being made about observation; second, the researcher intervenes in the problem setting
3. Action research is performed collaboratively and enhances the competencies of the respective actors. A process of participatory observation is implied by this goal. Enhanced competencies (an inevitable result of collaboration) is relative to the previous competencies of the researchers and subjects, and the degree to which this is a goal, and its balance between the actors, will depend upon the setting
4. Action research is primarily applicable for the understanding of change processes in social systems.” (Baskerville, 1999: p6-7).

The approach adopted for this research is characteristic of “canonical”<sup>2</sup> action research as it was originally formed but it also entails specifications relevant to Information System action research, as defined by Baskerville (1998, 1999). When defining the role of the researcher in action research, Lewin (1951) emphasizes the cooperation that must exist between the researcher and the organisation “studied”. He claims that if the objective is to produce knowledge that is relevant both for practice and research, then practice and research must be linked methodologically.

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<sup>2</sup> As described by Baskerville (1998)

Thus, Lewin (1951:169) states that if this methodological link is managed correctly, then action research can provide responses to theoretical problems while reinforcing the understanding of social practical problems that can be used to solve these problems. Hatchuel (1994) emphasizes the need to set up an intervention mechanism as well as a knowledge approach. The implementation of the intervention mechanism creates new relationships that aim to develop a dynamic of knowledge creation as well as confront the researchers' and the actors' knowledge. This type of methodological background is used for the design and development of a DA based on a case study involving an intense collaboration between project researchers and water resource managers.

### ***Research questions***

One of the characteristics of action-research is that research questions cannot all be defined *ex-ante*. In the context of an overall, broad research objective (here, the development and application of a DA tool for water resource management), focused research questions emerge from the researcher's practice and interaction with stakeholders. In the course of activities to develop and test the DA according to end-users' needs, it became clear that the following points would constitute key-research questions:

- What are the demands and constraints for designing a DA for water resources management in the context of IWRM?
- How does the operational context and practical demand of water resource management interact and influence the development of a DA?
- Can existing development methods be used to develop a DA that fits the operational context of IWRM?

These focused questions formed the basis of the research as field work progressed. They were translated into precise objectives and activities supported by specific methods, as shown on Table 1. The methods are described in detail in the next section.

*Table 1: Research questions, objectives, activities and methods*

Research questions	Objectives	Activities	Methods
A. What are the demands and constraints for designing a decision aid for water resources management in the context of IWRM?	A1. Examine the “state of the art” of software development in general and DA in particular.	Assess current status of technology and DA developed and guidelines for DA design and development. Identify common problems limiting the use of DA and the proposed solutions.	Review of existing literature.  Meetings with international and local researchers and donors
	A2. Assess the requirements of IWRM concerning the development of DA	Assess current guidelines for DA design following the IWRM guidelines	Review of existing literature on IWRM, its implementation and the implications for the DA design. Meetings with international and local researchers.
B. How does the operational context and practical demands of Water Resources Management interact and influence the development of DA?	B1. Understand and capture the needs of water resources managers, in particular those of river basin authorities, and the implications for DA development.	Identification of key stakeholders and end users of the DA	Workshops Key informants interviews Review of literature on the local management of water resources
		Understand the operational context of WRM and practical demands of water resources managers.	Key informants interviews and Observation/discussion with end-users
		Observe the influence of end-users involvement on the design of the DA	Analysis of project documents to understand how end-users requirements were “translated” into design requirements.
	B2. Devise a conceptual DA taking into account A1, A2 and B1.	Design a DA for WRM	Paper prototyping (interviews and workshops)
C. Can existing development methods be used to develop a DA that fits the operational context of WRM?	C1. Test the usability of the conceptual DA (B2).	Develop different versions of the DA for WRM	Iterative approach: design, data collection, modelling, programming, prototyping and trainings
	C2. Examine the impacts of the development methods on the DA developed	Compare and assess the DA contents and purposes with the operational context.	Prototyping, trainings, key informants interviews and evaluation of the different versions of the DA



## **1.8. Methods**

The research questions were addressed through an interdisciplinary and empirical study of the process of development of the DA. The study mobilized different disciplines such as participatory research approaches, management sciences, natural resources management, modelling and software engineering sciences. The development process from the first steps of design to the delivery of the tool was explored through meetings, workshops and interviews. After general and context-specific literature review, insights were generated regarding the role of the proposed DA as a tool for implementing IWRM and as a tool for improved decision-making by local water resource managers. This was done through further interviews, meetings and observations with end-users. Paper prototypes were used during some of these meetings and workshops to allow user validation of system design. Training activities with final users and DA specification prototypes were used to test and validate the different versions of the DA. The use of evolutionary prototypes (from paper-based to working model prototypes) was part of an iterative cycle that involved prototype reconstruction and user evaluation until the final version of the DA was achieved. Training sessions with users generated significant results which helped adjust research sub-objectives. Interviews were conducted (after the development phase) to obtain further user feedback which was then used to make final conclusions and recommendations.

The selected methodological approach belongs to Information System Action Research (ISAR). Baskerville (1999) classified the different methodologies that belong to Information System Action Research and characterised each of them depending on the process model, the typical involvement and the primary goals that is used by each methodology (Table 2).

Table 2: Information Systems Action Research methodologies in the literature and in the present work (modified from Baskerville, 1999: 96)

ISAR approaches	Process model			Typical involvement			Primary goals			
	Iterative	Reflec- tive	Linear	Collabo- rative	Facilitative	Experi- ment	Organisational Development	System design	Scientific knowledge	Training
Canonical AR	•			•			x		x	
IS prototyping	•			+	+				•	
Soft system	•				•		x	x		
Action science		•			•		x		x	
Participant observation		•				•			•	
Action learning		•				•				•
Multiview			•	+	+	+			•	
This research	•			x	x			x	x	(x)

Key: • signifies a dominant characteristic, + (or) signifies characteristics that will dominate in different studies, x (and) signifies characteristics that may occur together in the same study

Among the different types of action research methods presented by Baskerville (Table 2), the two main approaches used in the present work were canonical action research and Information system prototyping. Canonical action research was defined by Lening (1980, in Baskerville, 1999) as “Action research which simultaneously assists in practical problem solving and expands scientific knowledge, as well as enhances the competencies of the respective actors, being performed collaboratively in an immediate situation using data feed back in a cyclical process aiming at an increased understanding of a given social situation, primarily applicable for the understanding of change processes in a social system and undertaken within a mutually acceptable ethical framework.”

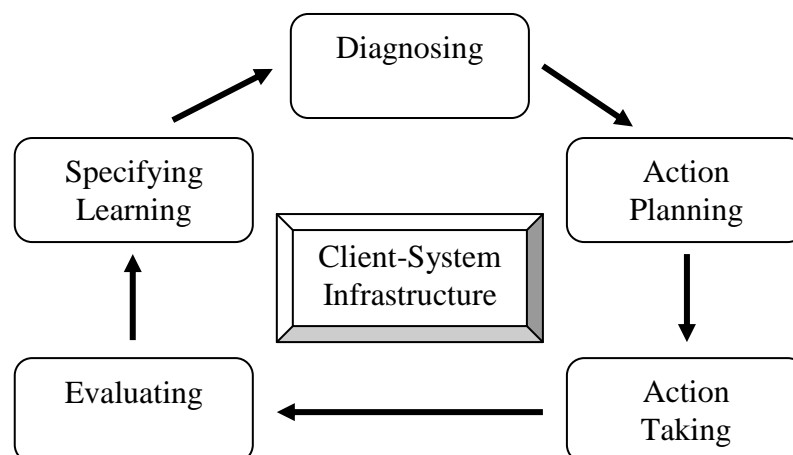
The process model used in this research is iterative. The typical involvement is both collaborative and facilitative while the primary goals of the research are system design and the generation of scientific knowledge. These characteristics fit perfectly with the two objectives of the present work, i.e. to design and develop a DA for a better management of water resources in the UGRRC and to generate knowledge concerning

the needs of the targeted institutions and the development of such DAs. The research also considered that training was a goal, but of less importance; “training” as a primary goal is usually linked to action learning research. However, the training and organisational development components could as well be considered part of the RIPARWIN project which also aimed at improving the management of the RBWO and the building capacity of water managers. Nevertheless, these were considered as indirect goals by project partners and are therefore not “ticked” in Table 2.

Baskerville (1999) and Kyng (1991) consider that the involvement of researchers in the targeted institution is dominantly collaborative in action research and either collaborative or facilitative in IS prototyping. In the present case-study, the involvement of the researcher was successively collaborative (during the development of RUBDAv1) and facilitative (during the development of RUBDAv2) (Table 2).

The iterative nature of canonical action research and IS prototyping research are well defined in the literature (e.g. Baskerville 1993, 1999; Susman 1983; Courbon 1995). Although the way the different phases that build an iteration cycle may vary slightly between authors, the generally agreed phases are those proposed by Susman (1993): Diagnosing, Action planning, Action taking, Evaluating, Specifying and Learning (Figure 1). These research phases are conducted in a research environment constituted by what Susman (1993) names the Client-System Infrastructure.

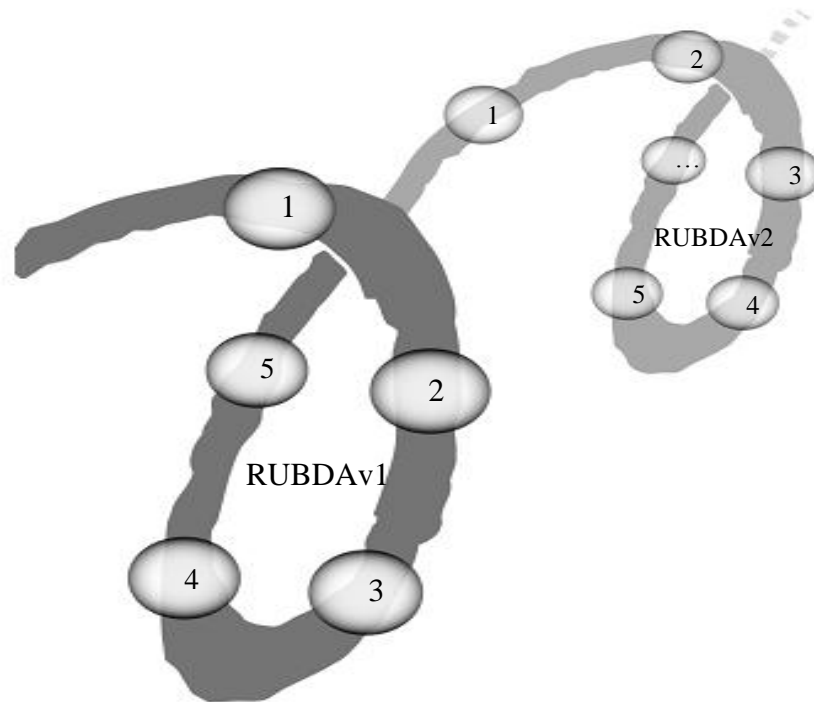
*Figure 1: Canonical action research process model drawn from Susman (1983)*



The five phases of the canonical action research process model appear similar to phases used in software engineering. Nogier (2005) describes the five successive phases of software development as: 1) evaluation (of the existing context and constraints), 2) design (of the conceptual software), 3) validation of design (using prototyping), 4) development and distribution and 5) users feedback and surveys (to improve the next version of the software). The first two phases are indeed very similar to what is described in action research. They are called Diagnosing and Action Planning by Susman (1983) and Evaluation and Design by Nogier (2005). The following phases differ slightly because the Action Taking phase defined by Susman (1983) is divided by Nogier into two phases, “validation of design” and “development”, whereas the last two phases “evaluating” and “specifying learning” are combined by Nogier (2005) in one phase called the “Users feedback and surveys”. Although the phases are defined differently, the activities and their sequence are similar and they are both part of an iterative process model in which the end of the cycle provides the lessons/knowledge necessary to start the following cycle.

The present work was conducted on the basis of two main iterative cycles, corresponding to the development of the two versions of RUBDA. In reality, the development of each version involved many more iterative cycles than the two main ones because of the “intermediate” prototypes that were developed as well as because of the specific modules or components that were developed separately. Since the output of the diagnosis/evaluation phases of the two main cycles (the understanding of RUBDA end-users needs and their translation into DA specifications) differed considerably, the type of DA designed and developed varied and the approach and the involvement of the researcher differed. The diagnosis conducted at the start of the second iterative cycle was fed by the specific learning generated during the first cycle. The process model appears therefore as an ellipsoid combining the two cycles as shown on Figure 2.

Figure 2: Schematic of the two cycles of the research process model.



\* Numbers refer to the successive phases of software engineering defined by Nogier (2005).

The evaluation/diagnosis phase of the first development cycle involved a literature review, conducting large seminars and workshops as well as individual interviews with end-users. The outputs of the workshops and interviews were as well used for the second phase (the design). The third phase, the development, involved modelling and programming work while the last two phases of the first iterative cycle were conducted in the context of a “training” activity where users tested and commented on the DA. The problems and comments made by the participants were used to launch the development of the second version of the DA. The second cycle evaluation phase was therefore shorter, as it relied on the conclusions and learning generated during the first cycle. The second and third phases involved as well modelling and programming work while training sessions were also used during the last two phases.

As noted by Courbon (1995), the scientific value of action research comes from the capacity of the researcher to take distance from his role and activities as an actor of change in the targeted environment, in order to reflect on the process and produce

scientific knowledge. Courbon (1995) adds that this “observation” is critical as it forms the basis of the scientific argument and of the research’s contribution. Apart from personal notes taken along the development process, a literature review and the analysis of project documents were used to reflect on the development of the DA. These are described in the following paragraphs.

#### *Literature review*

My work started with an analysis of the status of present trends in modelling and DA development sciences within the context of IWRM. This served as a basis for the development of a conceptual DA. I also attended workshops and seminars with researchers from international research centres dealing with water issues. These workshops were an opportunity to confront the conceptual DA to members of the international research community promoting IWRM and the use of integrated DAs for its implementation. The literature review and analysis of the workshop outputs contributed to the understanding of the requirements of IWRM and its implications for the design of DAs.

#### *Development of a Decision Aid*

Two main versions of the DA were produced, RUBDAv1 and RUBDAv2. The development involved modelling and programming. The two versions of RUBDA were programmed in FORTAN 90 (modelling) and VISUAL BASIC 6.0 (interface and modelling). I did the programming work, assisted by a software developer while based in Tanzania, before and after DA user training sessions. Efforts were made to involve Tanzanian stakeholders and targeted users as much as possible (especially during the design phase). Several prototypes were developed (including paper prototypes) that led to the development of two main versions of the DA (Chapter 5 - 5).

#### *Interviews*

Interviewees were selected from the catchment management agency, local governmental agencies and NGOs. The questionnaires used for interviews (see appendix A) served more as a basis for discussion than as a fixed structure for answers (semi-structured interviews). The questionnaires covered a large range of issues, varying from: i) technical questions about user requirements in terms of outputs, units, indicators or scenario to be run; ii) capabilities of the interviewees to use computers and type of

computers used; iii) water management tasks achieved; iv) position in the institution; v) understanding of the problems related to water management in the catchment; vi) views concerning the solutions and responsible potential stakeholders for resolving these problems; vii) other potential interviewees from inside and outside the institution that should be involved in the development of the DA. Both the conceptual DA and the questionnaire evolved during the process as more points of views were taken into account. After the interviews, the informants received the filled questionnaires for feedback and validation in order to improve the accuracy, the completeness and the credibility of the survey and of the analysis. In some cases, “member checking” was as well done during and at the end of the interview process.

### *Training*

Several training events were organised at different times during the development process. These events were aimed at testing and evaluating the different prototypes of the DA and were used to improve user-designer communication. The various trainings are presented in detail in the results chapters.

### *Analysis of project documents*

Project documents, primarily from the RIPARWIN project such as reports, meeting notes, workshop proceedings or progress reports were used as sources of data in order to understand and assess the different phases of the DA design and development. These data were extremely useful to assess the involvement of end-users and the evolution of the DA specifications during the different phases of the DA design and development.

## **Study Area**

This research was conducted in the Upper Great Ruaha River Catchment (UGRRC). The Upper Great Ruaha Catchment is a sub-catchment of the larger Rufiji Basin spanning from central-south Tanzania to the Indian Ocean. The UGRRC catchment presents a number of favourable conditions for the implementation of the research described above. The UGRRC also offered a unique opportunity in terms of financial and technical support for the development of a DA through the on-going RIPARWIN cooperation project (Raising Irrigation Productivity And Releasing Water for Intersectoral Needs). In response to a former cooperation project’s recommendations

and on request from the Rufiji Basin Water Office, RIPARWIN decided to develop a DA for the management of water resources in the UGRRC. A detailed description of the case study area is given in Chapter 3.

## **1.9. Thesis organisation**

This chapter (Chapter 1) has introduced the importance of IWRM at world level and in the African context where DAs are seen as part of the solution to improve water management. Objectives, research questions and methodological approach are also presented in Chapter 1. Chapter 2 is a review of literature about the development of DAs for the management of water resources. The review progresses through the history of the concept of IWRM, it shows that IWRM has been guiding the intervention of donors and development projects in sub-Saharan Africa. It describes the framework within which DAs for WRM have been developed. The literature review on Information Systems in general and on DAs in particular pays special attention to the problems and solutions that affect the usefulness and use of DAs. Chapter 3 starts with a description of the case study area and is followed by a description of the main challenges and stakes faced by water managers and water users. This chapter explains how the local context has led to the identification of the need for a DA for WRM.

Chapters 4 to 6 present the results of the study. Chapter 4 examines the users' involvement during the first phases of the project, from the inception to the design of the DA. The outputs of the participation process are carefully analysed to assess the manner in which users' requests were "translated" into design requirements. Analyses show that although users were actively involved in the design their requirements were not captured as expected. The design was therefore mainly influenced by the requirements of the project partners and the donors. Chapter 5 presents the development of the two versions of the DA. This chapter elaborates on the development methods used and on the choices made by the developers in response to local and project constraints. The chapter also presents outputs of users' training. It shows that the first version of the DA, developed as a research DA for the implementation of IWRM, did not meet the requirements of the users and that the adoption of methods derived from software engineering and project management to build the second version of the DA



could generate a more user-oriented DA. In Chapter 6, the final version of the DA is presented, tested and evaluated using case study scenarios in order to assess its usability and its ability to assist the users to manage water resources more effectively.

Finally, Chapter 7 draws out the implications, both theoretical and methodological, in relation to the study of the understanding of the needs of water resource management institutions for the development of a DA in a sub-Saharan Africa river basin. It is concluded that research-based DAs are only partially adapted to the operational reality of WRM and that it is necessary, but not sufficient, to use development methods derived from software engineering and project management to develop operational, user-based DAs.

A focus on actual end-users, i.e. water managers as they operate in Africa and the institutions in which they work, calls for methods where an active articulation between research and operational approaches is sought at all times in order to adapt to specific and changing circumstances. Unless this is achieved, observations and results obtained in the Upper Great Ruaha River Catchment show that African water resources are at risk.

## **Chapter 2 - Literature review**

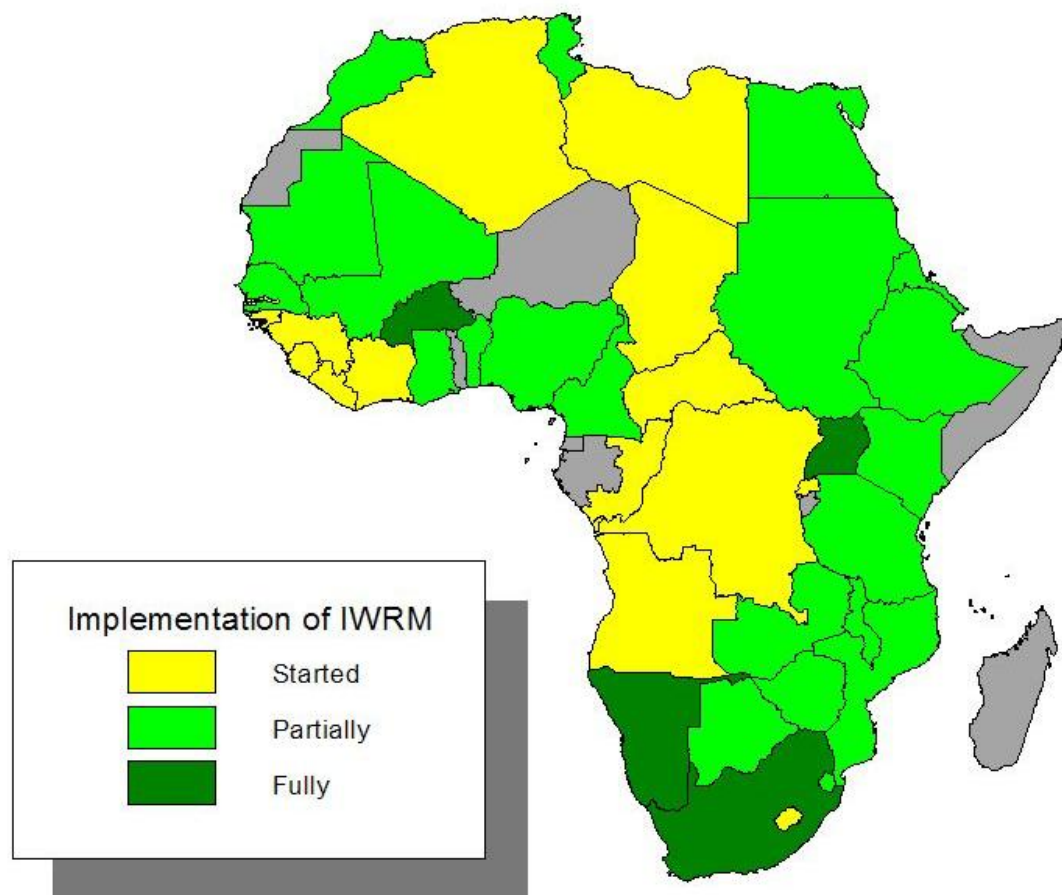
This chapter starts with a review of IWRM concepts as they were defined during international conferences and publications (section 1.1). The next section shows that the complexity of water management led to the development of a number of tools to help decision makers (1.2). After a brief description of the tools being developed, the literature review shows that Decision Aids (DAs) are seldom used. Reasons as found in the literature are presented, while the different modelling uncertainties are examined (section 1.3). Despite the experience of software developers and the number of DAs being developed, a question still remains about the effective use of DAs. The hypothesis presented here is that there is a gap between IWRM concepts and the operational reality faced by water managers (section 1.4), and that tools are mainly developed in the international, scientific context, guided by IWRM concepts, and far from operational reality. In section 1.5, the question is asked whether a DA can help implementing IWRM concepts in an operational context assuming that the factor lies in understanding users' requirements. Finally, software engineering science and methods are presented since they have been used in different contexts to better formalize user participation of DAs and have been applied in the present work for the development of the final version of the DA (section 1.6).

### **2.1. Integrated Water Resources Management or the water issue framework**

One of the key factors that feed into the risk that DA's are over complex relates to their capture and reflection of the complex integrated approach to water resources management. Toward the end of the 1990 and after many years of sectoral water management, the international community recognised a need to move towards Integrated Water Resource Management. The African Development Bank (1999) and other donors considered the orientations given by IWRM as a consensus. This led to many institutional reforms at national level in developing countries, especially in sub-Saharan Africa. Since DAs were perceived as one of the means that would contribute to efforts made by Governments and donors engaged in the implementation of IWRM, they must be analysed through the perspective of IWRM.

After the Johannesburg World Summit on Sustainable Development (2002), it was confirmed that the principles of IWRM were fundamental to attain the Millennium Development Goal for sustainable development. World leaders from 193 countries committed themselves to preparing national IWRM and water efficiency plans by 2005. The Global Water Partnership network (GWP, 2006) measured the movement towards water management reforms through IWRM plans, and a survey was edited in February 2006. It focused on policies, laws, plans and strategies prepared in 95 countries in order to assess initiatives to strengthen water resource management and the inclusion of IWRM principles in policy documents.

*Figure 3: Map of Africa showing the progress of IWRM implementation (Data from GWP, 2006; Grey: No data)*



The survey found a massive involvement in taking into account IWRM concepts: About three quarters of the countries assessed had met the target of initiating a process for the

development of IWRM national strategies (Figure 1). Criteria to classify countries were as follows:

- Fully: Plans and strategies that incorporate the main elements of the IWRM approach are in place.
- Partially: Process well underway to develop plans and strategies that incorporate the main elements of the IWRM approach
- Started: Process initiated but has not yet fully embraced the requirements of an IWRM approach
- Other: No reply or not included in the survey.

In the countries classified in the first two categories (fully and partially), the IWRM approach appears to be well accepted as the way forward for better water resource management and use. The remaining countries had made only limited progress and in many cases have expressed a wish to move forward and received support to do so.

### **2.1.1. Development of Integrated Water Resource Management as a concept**

There have been numerous ways of analysing the concept of IWRM in the past 50 years. Until 1980, integrated management was considered in a broader development context. Thus, Snellen and Screvel (2004) stated that:

*“Interpretation of integration is reflected in the title of many internationally-funded integrated irrigation development projects, where integrated referred to the supporting services needed to develop irrigated agriculture and not to the coordination between irrigation and other water uses” (Snellen and Screvel; 2004; 4).*

It was at the International Conference of Mar del Plata in 1977 that the need for coordination within the water sector was explicitly addressed, as follows:

*“Institutional arrangements adopted by each country should ensure that the development and management of water resources take place in the context of national planning and that there is real coordination among all bodies*

*responsible for the investigation development and management of water resources”* (Mar del Plata Action plan: recommendation No.2 on policy, planning and Management).

The Mar del Plata conference recommended the expansion of irrigated agriculture and raised some concern about community water supply, pollution of water bodies, and shared water supply. Coordination within the water sector was largely seen as a task for national governments. After 1977, the gap between the very ambitious integrated (holistic) approach advocated by the Mar del Plata conference and the lack of progress observed on the side of improvement of coordination within the water sector raised concerns (Snellen and Screvel; 2004; 6). The World Commission on Environment and Development addressed this issue in the Brundtland Commission report of 1987 (“Our Common Future”). The report proposed the concept of sustainable development to overcome the environmental problems caused by the development patterns that were leaving increasing numbers of people poor (Brundtland 1987). This was the launch of the sustainable development paradigm. To address the problem of environmental destruction and sustainable development, the General Assembly of the United Nations organised the United Nations Conference on Environment and Development (UNCED, or Earth Summit) in Rio de Janeiro in June 1992. At this summit, the need for coordination in the water sector was emphasized. The concept of holistic management (that can be read as integrated management) and integration of sectoral water plans and programmes within the framework of national economic and social policy” was described as of paramount importance (Agenda 21; Ch. 18 par. 18.6).

As a preparation for the UNCED with respect to water issues, the International Conference on Water and the Environment in Dublin, Ireland was organised in January 1992. The main success of the Dublin conference was that it focused on the necessity of integrated water management and on active participation of all stakeholders, from the highest levels of government to the smallest communities, and highlighted the special role of women in water management. The Dublin conference gave rise to four principles (Box 1) that have formed the basis for much of the subsequent water sector reforms.

**Box 1: The four Dublin principles (The Dublin Statement, 1992)**

**Principle No1. – Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment.**

Since water sustains life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems. Effective management links land and water uses across the whole of a catchment area or groundwater aquifer.

**Principle No.2 – Water development and management should be based on a participatory approach, involving users, planners and policymakers at all levels.**

The participatory approach involves raising awareness of the importance of water among policymakers and the general public. It means decisions are taken at the lowest appropriate level, with full public consultation and involvement of users in the planning and implementation of water projects.

**Principle No.3 – Women play a central part in the provision, management and safeguarding of water.**

This pivotal role of women as providers and users of water and guardians of the living environment has seldom been reflected in institutional arrangements for the development and management of water resources. Acceptance and implementation of this principle requires positive policies to address women's specific needs and to equip and empower women to participate at all levels in water resources programmes, including decision-making and implementation, in ways defined by them.

**Principle No. 4 – Water has an economic value in all its competing uses and should be recognised as an economic good.**

Within this principle, it is vital to first recognise the basic right of all human beings to have access to clean water and sanitation at an affordable price. Past failure to recognise the economic value of water has led to wasteful and environmentally damaging uses of the resources. Managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources. (The Dublin Statement, 1992)

The fourth principle became highly debated and was opposed by water professionals from the developing world. They argued that no water development initiative could be sustainable if water was considered an economic good without considering the issues of equity and poverty. Nevertheless, the Dublin principles significantly contributed to the Agenda 21 recommendations adopted at the Rio 1992 Earth Summit. As Rahaman and Varis (2005) state, the major limitations of the Dublin conference were that: 1) It was, for the most part, a meeting of experts rather than an intergovernmental meeting, especially lacking active participation from the developing world, 2) There were no IWRM implementation guidelines produced.

As a follow up to the Dublin conference, the Second World Water Forum was held in The Hague, Netherlands, in 2000. Unlike Mar del Plata and Dublin, this Forum did not just gather intergovernmental participants and experts, but included a range of stakeholders from the developing and developed world. This would become key to the Forum's success, and to its participants' satisfaction. Unlike Dublin, The Hague Forum carefully considered the outcomes of previous water initiatives and acknowledged water's social, environmental, and cultural values, while the main challenges to implementation were discussed extensively. Afterwards, the Forum's visions were converted into action programs for the participating countries. This led to the birth of the Global Water Partnership (GWP, 2000; 22), which defines IWRM as follows:

*"IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems."*

The Dublin principles and the GWP implementation guidelines have found universal support amongst the international community as the guiding principles underpinning IWRM. Although the need to manage water resources at catchment scale is not part of the Dublin principles, it is at the origin of IWRM and was to become the logical planning unit for IWRM. The GWP (2000: 24) states that:

*"The promotion of catchment and river basin management is an acknowledgement that these are logical planning units for IWRM from a natural system perspective. Catchment and basin level management is not only important as a means of integrating land use and water issues, but is also*

*critical in managing the relationships between quantity and quality and between upstream and downstream water interests.”*

### **2.1.2. A need for institutional change**

A traditional sectoral approach to WRM can lead to governing bodies representing conflicting interests. This is why there is a need to find appropriate ways to coordinate policy-making, planning and implementation in an integrated manner across sectoral, institutional and professional boundaries. Here lies the basic distinction between WRM and IWRM.

As stated by the GWP (2000), in order to achieve efficient, equitable, and sustainable water management, institutional change is needed. The traditional top-down approaches to management have to be supplemented by, and partly replaced by, bottom-up strategies to ensure that the water sector is demand-driven and can deliver welfare gains to the whole range of end users “from the level of the nation down to the level of a village or a municipality and from the level of the catchment or watershed up to the level of the river basin” (GWP, 2000; 33). The stakeholders to be involved are, apart from governmental agencies: Private companies, community based organizations with participation of women and disadvantaged groups, NGOs and other parts of the civil society.

For bottom up strategies to be effective, new institutions are likely to be needed. As stated in GWP, different approaches can be appropriate: In many situations it will be essential to create community based organizations, which can actively participate in the development and management of water supply systems. In other situations democratically elected and representative consultative committees and market mechanisms may be the appropriate means by which users can convey their demands for water goods and services to providers. Bottom up strategies mean that “an appropriate balance has to be struck between community level organizations and governmental bodies” (GWP, 2000; 46).



### **2.1.3. Government seen as an enabler**

In the process described by the GWP (2000), the government is seen as an enabler, regulator and controller more than a service provider. Policy making, planning, water allocation, monitoring, law enforcement and final conflict resolution still need to be the responsibility of governments. Other stakeholders, such as the private sector (corporate sector and community based organizations), may then provide water services subject to monitoring and control by some regulatory entity. Legislation provides the basis for government intervention.

A critically important element is the “integration of various sectoral views and interests in the decision making process, with due attention given to upstream-downstream relationships” (GWP, 2000; 38). The idea is to incorporate consultation and to seek consensus within ministries and government, as well as with other stakeholders located in different parts of a river basin. It is then possible to plan water allocation across the entire basin and to avoid misallocation of water resources to one particular sector when higher value uses and users are denied services. Putting on one table, and in a transparent manner for all sectors and stakeholders, the combined demands placed upon water (quantity and quality) will help determine what is feasible in order to achieve sustainable water resources management.

### **2.1.4. Multiple scales of action**

Implementation of IWRM is recognised to require different scales of planning (Gangbazo, 2004):

- State scale, where planning is performed by government bodies with the development of political, administrative and legal conditions ;
- River basin scale, where river basin management organisations define the solutions to achieve the goals of water protection and rehabilitation, prepare investment programs, and coordinate the different actions. Those organisations are managed in collaboration with representatives of all stakeholders involved. In France for example, the whole country has been divided by law in six water agencies, following natural hydrological divisions. Each agency has its

programme, implemented after approval by a committee of the representatives of all stakeholders. The Committee also decides on fees, grants and loans.

- Project scale, where stakeholders are realizing projects designed following a dialogue organized by the river basin organisation, in order to achieve the goals of water protection.

The catchment management organisation, or agency, plays a central role in IWRM, as it is the central place for consultation and dialogue between stakeholders. It is its responsibility to ensure that dialogue is taking place at local and regional scale, and to define the water-planning program, with public participation (Regroupement des organisations de bassin versant au Québec, 2003).

For Van der Zaag (2005: 868), *“the new water organisations should primarily serve as consultative bodies that ensure that developments throughout the catchment are consistent”, but they should not necessarily have executive functions. Integrative capacities can be developed at the district level where the various government departments participate in implementing multi-sector rural development programs. “Creating parallel structures may lead to misunderstanding, competition and even un-coordinated developments”.*

Although catchment management agencies are given the central role for managing water resources and implementing IWRM, local governmental agencies, such as district councils, still have a key role. It is therefore important to consider both catchment management agencies and district councils when dealing with the management of water resources.

It is critical to consider the scale as an important factor when developing a hydrological model or a DA because it can have an impact on their usability and use. The scales used in the tool and the way the modelled system is sub-divided (e.g. sub-catchments, hydrological units) and displayed must match the way it is divided by water resources managers. The acquisition of inputs and the outputs data generated (results) must be displayed at scales that fit the “management units” used by the end-users. As it appears later in the thesis, this was an issue for the usability of the DA developed in the case study.

## **2.2. Implementing IWRM: Tools and methods**

As described above, implementing IWRM is a complex task. A solution proposed by scientists and the international community is to provide water managers and other stakeholders with various technical tools (or *instruments*, sometimes *methods*) that aim at supporting the management of water resources.

IWRM promotes the use of instruments for its implementation. These instruments comprise among others legal and economical instruments. Tools and instruments developed to assist IWRM are of different nature. They range from paper based or physical role-playing games to computer based modelling and scenario simulation models such as DAs. As we have seen, managing water resources involves a large variety of issues, stakeholders and institutions.

Most institutions and organisations, including decision makers and managers from river basin authorities, have adopted IWRM principles. These managers are faced with management on an every day basis that does not necessarily fall within IWRM. Yet, their responsibilities are important and the consequences of their decisions can have a great impact both on humans and the environment. Until the IWRM implementation guidelines are fully adapted and ready for full implementation, managers will remain in the situation of having to choose between very attractive but rather theoretical IWRM principles and the reality of the local context. Therefore, the present work attempts to generate knowledge towards improving the management of water resources, and then towards the implementation of IWRM. The study hopes to do so by improving the development of DAs. Improving the development of DAs means here to shift the overall aim of developers from trying to assist the implementation of IWRM to trying to assist water resources managers in their everyday responsibilities. Although the indirect aim is to improve the management of water resources, DA developers and their organisations are direct recipients of the study.

In an attempt to provide means of integrating land use and water issues at the catchment level, GWP (2000; 51) introduces the concept of instruments, described as:

*“... the tools and methods that enable and help decision-makers to make rational and informed choices between alternative actions. These choices should be based on agreed policies, available resources, environmental impacts and the social and economic consequences. A wide range of quantitative and qualitative methods is being offered by systems analysis, operations research and management theory. These methods, combined with a knowledge of economics, hydrology, hydraulics, environmental sciences, sociology and other disciplines pertinent to the problem in question, are used for defining and evaluating alternative water management plans and implementation schemes.”*

The use of instruments as promoted by GWP (2000) includes a large range of tools and methods. It promotes the use of tools such as models and information systems for water resources assessment (to evaluate resource availability and demand), for communication, as well as for water allocation and conflict resolution. This need for tools to enable water managers to implement IWRM principles in catchments by integrating knowledge on hydrology, socio-economics and environment has been largely taken up by the international community, as well as by multilateral development banks such as the World Bank (1993), the Asian and the African Development Banks (1999), as well as UN agencies (FAO, 1997), the European Commission and other donors.

Most real world problems involve uncertain information, and whether we are dealing with scientific, engineering, or personal problems, we are forced to make decisions that are based on incomplete knowledge. It is to assist decision makers in water management that modellers have attempted for the last 50 years to build models of the environment. Models should be seen as complement to other tools used to provide understanding of real world problems. A model is any conceptual representation of a process or processes within a physical, biological or social system (Namusasi, 2001; Baird, 1995). A mathematical model can vary in complexity from a simple one line equation or algorithm to a computer code consisting of many thousands of lines. Models have limitations in that they can only predict from prescribed relationships and supplied

datasets. Generally speaking, models have two major functions (Beven, 1989). First, they can be used to discern the nature of the physical processes operating in a system and, second, they can be used to make prospective scenarios concerning the future behaviour of that system.

### **2.2.1. Hydrological Models**

There can be no doubt that modellers working for managers recognize the hydrological nature of the basin they are modelling. Because of this, hydrological models are often key components of a user model.

Hydrological modelling is a procedure which simulates the conversion of precipitation to runoff through natural processes such as evaporation, infiltration, transpiration, percolation, surface flow, interflow and groundwater flow (Kite and Droogers, 2000; Baird, 1995). Hydrological modelling has been developed from the need to predict the hydrological output such as extreme events, e.g. floods and low flows, to extrapolate hydrological data series and to make decisions in relation to planning, design, operation and management of water related structures.

There are many types of hydrological models that can be distinguished on the basis of their function, structure, level of spatial dis-aggregation and simulation process. Nevertheless, many of the models share structural similarities, because their underlying assumptions are the same. Models can take a variety of forms: physical, analogue or mathematical. Mathematical hydrological models can be classified into two primary groups: Deterministic and stochastic. Deterministic models are based on assumptions that all inputs, parameters and hydrological processes are free of random variation and known with certainty (Baird, 1995). At the micro-scale, all hydrological processes may be deterministic (Batchelor et al., 1998). Stochastic models describe the unpredictability of nature and represent hydrological events as probability distributions. Stochastic models require long time data series to derive probability distributions.

Deterministic models themselves can be divided into several sub-categories. Based on spatial distribution, deterministic hydrological models may be classified as lumped,

semi-distributed or distributed. Lumped models (e.g. Sacramento Soil Moisture Accounting Model – Burnash, et al., 1973) ignore or average spatial variations of the hydrological variables and parameters e.g. rainfall, evapotranspiration, soil, and slope. Physical processes are here represented directly by sets of equations. Semi-distributed models (e.g. TOPMODEL – Beven and Kirkby, 1979) are similar to lumped models but spatial resolution is accounted for by using probability distributions of input parameters across the basin. On the other hand, distributed models (e.g. SHE – Abbott et al., 1986), although similar to lumped models in that a physical approach is taken, do consider spatial variations by dividing the basin into component areas.

Based on the knowledge base upon which the models are developed, deterministic hydrological models may further be classified as (i) conceptual models, if they are developed on the knowledge base of the relevant physical, chemical, and biological processes that act on the input to produce the output, or (ii) empirical models in which outputs are inferred from statistical relationships derived between the outputs and selected inputs. Other sub-categories of deterministic models are water balance models, which express causal relationship between hydrological processes to estimate average annual or monthly water balance components (usually stream flow) and finally hybrid models, which make use of one or more of the above approaches.

Further sub-categorisation of deterministic hydrological models is done on the basis of how model parameters are determined. Measured parameter models are those in which model parameters can be determined from system properties, either by direct measurement or by indirect methods based upon the measurements. Fitted-parameter models, on the other hand, include parameters that cannot be measured. Instead, the parameters are found by fitting the model with observed input and output data. In general, empirical models have the least-demanding input requirements (although large amounts of data may be required to develop the empirical relationships that are used) while distributed models require more data.

### **2.2.2. Models for management: Decision Aids**

In the field of water management, there has been a recognition that the conventional ways of allocating natural resources among competing sectors has proved to be inefficient largely due to a lack of integrated approaches for comprehensive understanding of the river basin characteristics and inter-linkages between components. This has driven the need to develop and apply integrated tools to support decision-making processes.

Rapidly advancing computational ability, the development of user-friendly software and operating systems, and the increased access to and familiarity with computers among decision makers have increased the use of DAs. In the past ten years, an increasing number of sophisticated model-based information systems supporting policy-making processes have been developed. This trend is propelled by a growing belief that policy-making should be based on an integrated approach. Policy makers and natural resource managers are confronted with this complex reality on a daily basis and have to be able to rely on adequate instruments enabling them to understand better and anticipate the effects of their intervention as fully as possible (Oxley, 2004). To respond to the demand of natural resources managers, the concept of Decision Support Systems (DSS) appeared. Whereas models could be defined as simplified descriptions of a system to assist calculations and predictions, a DSS is a means of collecting data from many sources to inform a decision. Information can include experimental or survey data, output from models and expert or local knowledge. Georgakakos et al. (2002) define a DSS as an interactive, computer graphics-based program incorporating appropriate mathematical optimisation and/or simulation models, sometimes together with more qualitative rule-based or linguistic algorithms, and designed to address the questions or issues pertaining to specific problems at specific sites. Adelman (1992) has defined DSSs as:

*“interactive computer programs that utilize analytical methods, such as decision analysis, optimisation algorithms, program scheduling routines, and so on, for developing models to help decision makers formulate alternatives, analyse their impacts, and interpret and select appropriate options for implementation”.*

Watkins and McKinney (1997) defined a DSS as an integrated, interactive computer system, consisting of analytical tools and information management capabilities, designed to aid decision makers in solving relatively large, unstructured problems. A common idea explicit in each of these definitions is that DSSs integrate various technologies and aids in option selection. Implicit in each definition is that these are options for solving relatively large, unstructured problems. The key purposes of DSSs are thus (Sprague and Carlson, 1982):

- to assist managers in their decision processes in semi-structured tasks
- to support rather than replace managerial judgment
- to improve the effectiveness of decision making rather than its efficiency.

In the past few years, some developers have tried to push the concept of helping decision a bit further and have created the concept of Decision Aid. These two designations, DSS and DA, are generally used interchangeably. For more clarity, the term Decision Aid, and its acronym DA will be used in the present study.

As described above, in the field of water management, developers have tried to assist water managers by providing them with tools that deal with the water system in an integrated way, following the principles of IWRM. Despite efforts invested in the development process of DAs for the management of water resources, the practical application of these tools still runs behind their availability (Mc Bride, 1997; Newman et al., 1999; De Kok, 2003).

### **2.3. Explaining the failures of Decision Aids**

*« Despite of the effort invested... and the growing experience in developing integrated systems models, practical applications of decision support systems still run behind their availability » (De Kok, 2003).*

As stated by De Kok (2003), while a great amount of work has been achieved on the development, assessment and evaluation of DAs to identify the key features reducing the chances of developing DAs that are not used, the acknowledgement of failure remains: Policy makers and managers are still not sufficiently using DAs. A large



number of factors have been identified in the literature as the reasons explaining the failure of DAs. These factors are linked to different parts and processes of the development of DAs, starting from the modelling *per se* to the design of the tool, including the involvement of users.

Several modelling guidelines and methods have been developed in response to the increasing number of malpractices and mistrust to the credibility of models (Refsgaard et al., 2003) that directly affect their use. It is important to recognise that mistrust in DA outcomes will result in DAs not being used. Many models used in DAs are simplified abstractions of complex natural systems characterised by non-linearity and inter linkages between different components. They have therefore inherent components of uncertainties in their behaviour (Saloranta, 2003). Funcowitcz and Ravetz (1990) give a typology of the uncertainties that characterise and alter the scientific “appropriateness” of models. The three main types of uncertainties that were summarised by Saloranta (2003, 324-5) are as follows:

***“Technical Uncertainties (Inexactness):*** *These uncertainties are connected to the model parameter values and to the quality of input data. Technical uncertainties in model output results can be identified by sensitivity and uncertainty analysis techniques...*

***Methodological Uncertainties (Unreliability):*** *These uncertainties stem from modelling methods, arising from the fact that models, their structure, functional relationships, spatiotemporal scales and discretisation, numerical approximations (algorithms, parameters), etc., are always incomplete abstractions of the reality of the natural systems. Methodological uncertainties are closely related to the relevance of the modelling task in question, they are difficult to quantify, and thus their assessment is generally restricted to qualitative statements. Peer agreement on the modelling methodology, amount of evidence, and level of scientific understanding can be fairly good indicators for methodological uncertainties.*

***Epistemological Uncertainties (Border with Ignorance):*** *These uncertainties are connected to the limits of scientific knowledge, i.e., to incomplete conceptual understanding of the natural systems (especially in chaotic and complex systems, and novel research fields), and thus ignorance of processes owing to lack of*

*knowledge. In other words: “we don’t know what we don’t know”. Epistemological uncertainties are very hard to grasp and assess. However, we can at least become aware of their existence and try, for example, to describe a range of possible “imaginable surprises”*

Uncertainties linked to the quality of input data and parameter estimates or to assumptions are reducible (Refsgaard et al., 2004). Through sensitivity and uncertainty analysis techniques, technical uncertainties can be reduced. Other uncertainties, such as those linked to the limits of scientists’ ability to handle the real world’s complexity, need to be managed and reduced, as they cannot be eliminated. As Saloranta (2003; 325) argues:

*“... in order to obtain higher quality information in policy contexts, uncertainties must be effectively managed, not banished. Good uncertainty management and communication are especially important in policy relevant science...”*

Argent (1999) adds that users must be involved in a process that raises their awareness of the influence of uncertainties in the technical knowledge if model builders want their models to be used. DAs for the management of water resources are based on hydrological modelling and therefore possess uncertainties linked to the modelling as defined above. But DAs go beyond modelling as they intend to support decision-making. Thus, problems faced by information technology, connected to the understanding of decision mechanisms or the ease of use of graphical interfaces, complicate the task of ensuring and evaluating the acceptance of DAs.

To determine the causes of this acceptance, developers have tried to evaluate DAs, their use and their ability to successfully support decision makers (Brooksbank, 2001; Finlay and Wilson, 1997; Harrison and Pelletier, 2001; Wyatt and Smith, 2000; Zapatero, 1996). Mysiak et al. (2003) provides a summary table of some of the agreed success factors for DSS (Table 3). This evaluation grid was applied to the DA developed in the present work (Chapter 6).

*Table 3: Various features and criteria used for the evaluation of DSS (Mysiak et al., 2003)*

Subject of validation	Examples of measurements
(DSS) Development process	Involvement of future users in early development phases, appropriately defined system requirements, evolutionary system development, clear definition of beneficiaries.
DSS components	Precision of models, quality of data, user interface, reporting system to choice of suitable technology and management of data, complexity of DSS and data inputs.
Decision process	Appropriateness of logical process followed when using DSS, number of alternatives explored by DSS, internal communication, correspondence to and appropriateness for decision organisation
Decision output	Quantification profit/loss from DSS usage, consensus achieved among decision-makers, savings of time or other resources through DSS usage, contribution to organizational efficiency, consistency of solution
User satisfaction	Degree of confidence in results derived by DSS, acceptance (willingness to change current management methods), improvement of personal efficiency, correspondence of DSS output with decision-making style, users' understanding of implemented models

### **2.3.1. User involvement in DA development: reducing chances of failure**

Although there are large numbers of different approaches and different causes pointed out, there is a common agreement that the lack of user participation during the development process is a critical factor.

User participation is described as a compulsory component. If users are not involved enough (and “properly”), failure is almost certain. The shift from “simple” modelling for scientists to DAs built for managers has forced developers to acknowledge that developing better platforms for decision making required user-oriented tools. In the literature, there is unanimous agreement that user involvement is a prerequisite to

successful adoption and use of DAs. Thus, De Kok (2003, 574) reviews three different DAs and concludes that although there are challenges linked to the modelling or the programming choices made, “end-user participation, a clear goal, and experienced project management are key success factors.” Early involvement of users is also part of efforts undertaken towards increasing the relevance of DAs for policy-makers and managers (Welp, 2001; Mysiak, 2005). The involvement of users allows a better understanding of their requirements and expectations (Welp, 2001; Mysiak, 2005). The choices upon input/output information, specification of indicators, parameter editing and output presentation must be made with the participation of users in order to develop DAs that fulfil their requirements (Argent, 2001; Welp, 2001). Argent (1999; 697) describes the various steps during which stakeholders were involved in the development of a DA related to nutrient loads in the Goulburn River of Victoria (Australia) as follows:

*“1) processes to be included in the system simulation; 2) the output parameters of the models; 3) analysis of nutrient export concentrations from different land uses; 4) data collection on nutrient generation by different land use activities; and 5) the formulation of algorithms for assessment of the risk of blue-green algae blooms”.*

The continuous involvement of users during the development phase is critical, both for the relevance of the model’s contribution to the decision making processes and for the users’ trust and acceptance of the tool as they will be aware of the assumptions made and the limitations of the DAs (Welp, 2001). DA development generally involves users through workshops (Welp, 2001) organized on a regular basis throughout the development process. These workshops are intended to provide a means of understanding the requirements of users and test the various functionalities, results and interfaces of DAs. Workshops organized around evolutionary prototypes allow users to continuously evaluate the tool and contribute to its improvement. Mysiak (2005) examines the case of the MULINO DSS that used the release of three system prototypes during meetings with users to provide system’s developers with a continuous flow of feedback. Several authors raise the need to rely on a facilitator to assist in translating the qualitative judgments made by users into quantitative evaluations and inputs for DA builders (Soncini-Sessa, 2003; Welp, 2001).

The various factors identified in the literature as possible reasons explaining the failure of DAs can be grouped into five categories. These categories represent the DAs' development "domains" to which the factors of failure are linked to. The five domains are the modelling, the interface/ease of use, the results/outputs, the confidence/acceptance and the usefulness/efficiency. Table 4 summarizes the factors and solutions for DA failures in the different domains.

*Table 4: Factors, solutions and domains of reasons for failure from the literature*

<b>Domains</b>	<b>Factors</b>	<b>Solutions</b>	<b>References</b>
Modelling	Quality of input data Assumptions, uncertainties	Sensitivity analyses, data management Use model inside its scope	Funcowicz and Ravetz (1990) Refsgaard (2003) Saloranta (2003)
Interfaces Easiness to use	Complexity, not intuitive, portability, rapidity, help	Paper prototypes & workshops	Schultz, Argent (2003), Soncini- Sessa (2003), Mysiak (2005)
Results Outputs	Precision, units, display, Indicators, consistency	Problem identification, needs of users	Welp (2001), Saloranta (2003), De Kok (2003)
Confidence acceptance	Black box, trust, training	Awareness & continuous users' involvement Model transparency	Argent (2002), Soncini, De kok (2003), Saloranta (2003)
Usefulness, efficiency	Time saving, efficiency, users, adaptability	Technology, understanding of decision processes Exploit current knowledge of stakeholders	Argent (1999)

As can be observed in Table 4, solutions often lead to more user involvement, i.e. the organization of workshops and meetings to generate knowledge about users' requirements and evaluations of DAs. These meetings require facilitators to assist communication between model builders and users. However, most of the efforts towards improving the relevance and success of DAs are still focusing on the modelling and conceptualization.

#### **2.4. Two dimensions for IWRM: Theory versus reality**

IWRM has become a popular concept in recent years due to its amazingly attractive and persuasive nature. It has been embraced by most donors and governments. As shown by the GWP (2006) study, twenty-six countries in Africa are undergoing reforms to put in place IWRM plans. This shows how far IWRM has gone in terms of becoming the mainstream approach to water management. Nevertheless, the GWP (2006) study shows the status of IWRM policies, laws and plans, but not what is actually being implemented. Despite the apparent consensus on the validity of the concept, there has been growing concerns regarding its applicability, especially in developing countries (Biswas, 2004; Lankford et al., 2005). Thus, Biswas (2004) states that, “the current evidences indicate that irrespective of the current popularity of the concept, its impact to improve water management has been, at best, marginal”. Although there are doubts concerning the outputs of the implementation of IWRM, enormous efforts are made by developing countries to strengthen water resources management. These efforts include most of the time the reform of water and environment policies, laws, plans and national strategies.

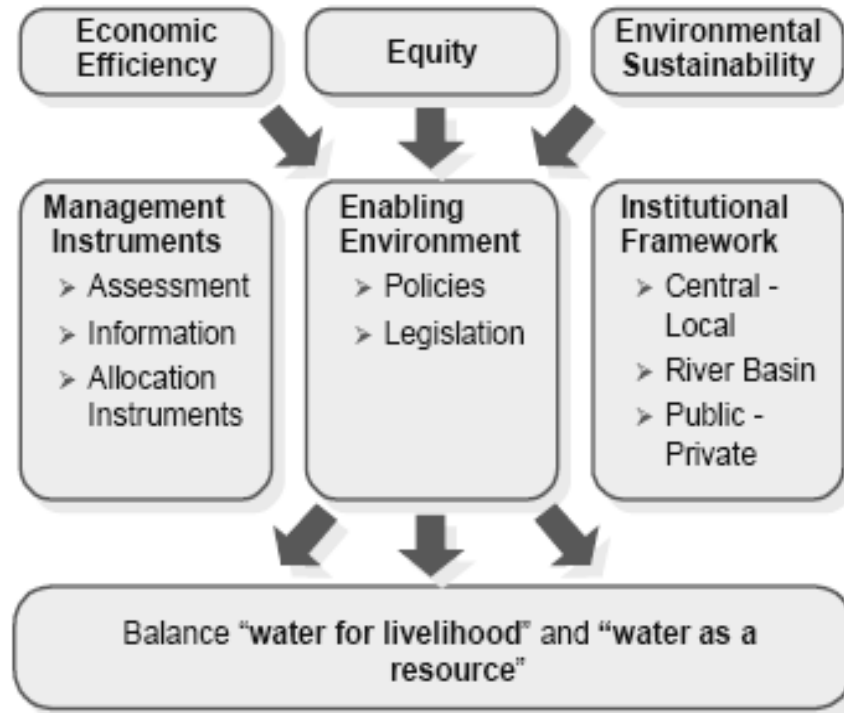
These reforms are implemented under the banner of IWRM and are guided by concepts promoted by donors and international institutions. As an example of these concepts, the GWP states:

*“Implementing an IWRM process is in fact, a question of getting the “three pillars” right: moving toward an enabling environment of appropriate policies, strategies and legislation for sustainable water resources development and management; putting in place the institutional framework through which the policies, strategies and legislation can be implemented; and setting up the management instruments required by these institutions to do their job.” (TEC No10)*

The three pillars concept of IWRM (GWP, 2004) is illustrated in Figure 4, which has appeared in many publications. The diagram shows that environmental sustainability, social equity and economic efficiency need to be simultaneously present and are essential to achieve the balance between the needs of societies and the environment.

Although there is nothing wrong in this diagram, it must be noted that it is an adaptation of existing sustainable development diagrams to IWRM.

*Figure 4: Diagram of the three pillars of IWRM (GWP, 2004)*



Although IWRM is widely accepted, Biswas (2004) claims that its definition given by the GWP is unimplementable due to its vagueness and “does not provide any real guidance to water professionals as to how the concept can be used to make the existing water planning, management, and decision-making processes increasingly more and more rational, efficient and equitable.” Figure 4 illustrates the vagueness of IWRM concepts. The three pillars concept has been widely re-used by donors (FAO (2004), IUCN (2005), UNESCO (2006)) and governments as a basis for institutional and legal reforms. The outcome of these reforms can be witnessed in many countries in Africa. These reforms resulted in new water policies and legal instruments to enable regulation and control of water uses, with e.g. the creation of basin authorities, water granting systems, pricing and instruments allowing public participation. Putting in place such instruments represents a tremendous impact of IWRM at national scale. There are now local governments and basin agencies that endorse and represent IWRM in many countries. If it is accepted that these “local” institutions aim at improving water management by implementing IWRM, the question is: Why is IWRM having such little

impact on the field? Some elements of answers could come from the GWP observation that “Institutional development is not simply about the creation of formally constituted organizations” (GWP, 2000; 45). It also involves consideration of a whole range of formal rules and regulations, customs and practices, ideas and information, and interest or community group networks, which together provide the institutional framework or context within which water management actors and other decision makers operate.

A key issue is the creation of effective coordination mechanisms between different institutions. It should not be assumed that integration, in the sense of organizational consolidation, automatically leads to cooperation and coordination which in turn leads to the improved effectiveness of water resource management. Fragmented and shared responsibilities are a reality and are likely to exist for ever. There are many examples where agencies or responsibilities have been merged without significant performance improvements. Conversely, there are several examples where the existence of effective coordination mechanisms has allowed problems to be handled despite the need to involve several agencies. It is clear that the simple act of putting all water functions within one agency will not necessarily remove conflicts of interest. Many authors point out to the lack of managerial capacity and co-ordination between management bodies as an explanation for poor management of poor natural resources. (Blagbrough, 2001; Lockwood, 2002; UNEP, 2005).

Mermet (1991) raises the need to reconsider management issues. He argues that the problem lies in who is considered as managing water resources and recognizes two main types of management: (i) the effective management of natural resources, defined as all human actions having an effect on the natural environment and; (ii) the intentional management, characterised by stakeholders and agencies attempting to have an impact, judged as positive, on the environment. He insists on giving high priority to effective management (practices and local arrangements of the users of natural resources) when proposing strategies for management of natural resources by catchment agencies. Intentional management agencies mainly represented by the catchment management agencies and local governmental agencies aim at implementing IWRM as it is imposed by water and environmental policies before dealing with effective management.



### IWRM as Theory

International Institutions

↓

Principles, normative, rhetoric, stakeholder disconnect

Economic Efficiency

Equity

Environmental Sustainability

Management Instruments

- Assessment
- Information
- Allocation Instruments

Enabling Environment

- Policies
- Legislation

Institutional Framework

- Central - Local
- River Basin
- Public - Private

↓


Balance "water for livelihood" and "water as a resource"

### IWRM as Operational Reality

Reactive management, uninformed, unplanned, daily management

↑

climate variability, new demands, demographic pressure, sectoral lobbying, finance, scale, Local & customary arrangements, etc. = RAPID CHANGE.



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water resources themselves. Instead river basin authorities have to respond to new demands, climate variability and other requests of water users very rapidly, with limited technical knowledge of the natural system.

Although employees from local governments and river basin authorities claim they are acting to implement IWRM, the reality of their activities does not allow them to do so. The split between IWRM as a theory described and promoted by the international community on the one hand and the operational reality as performed by local governments and river basin authorities on the other hand is described on Figure 5.

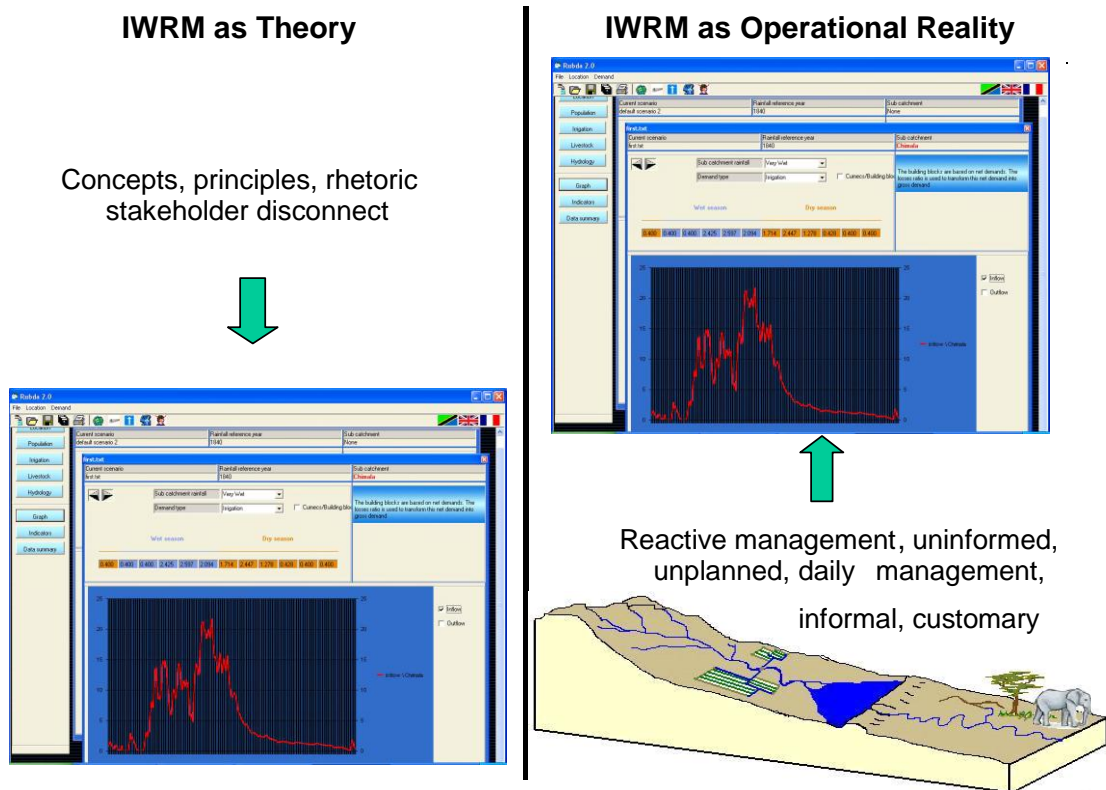
## **2.5. Can a DA be used to implement IWRM?**

The main observations from the preceding sections are:

1. DAs are usually developed according to theoretical IWRM concepts
2. Theoretical IWRM as defined by the GWP and promoted by most scientists and governments is hard to implement and far from the reality of water resources managers
3. There have been several attempts to understand why DAs are seldom used, but failure of use persists.

Building on these observations and if one considers that DAs are often not used although the sources of failure and their solutions have been identified, it becomes evident that there is another reason for failure. Combining this remark with the gap existing between IWRM concepts and operational reality leads to the following question: Could the failure of use of DAs be linked to the fact that DAs are developed according to theoretical IWRM concepts instead of the real needs of water managers to actually achieve their job?

Figure 6: Two ways of developing DAs for two types of IWRM?



In other words, and without minimizing the factors of failure identified in the literature, but instead adding on them, another factor of failure for the use of DAs could be the overall “spirit” within which these DAs are developed. Indeed, the need for user participation during the development of DAs has often been raised as necessary. But user participation cannot be fully accomplished because in essence it would require developers to fully follow the needs of users. Instead, DAs in the field of water management firstly follow the IWRM concepts and then try to involve users, and it can thus be argued that it is not always possible to answer the requirements of users when following IWRM concepts. Figure 6 illustrates two ways of developing a DA: on the left side, a top-down development, guided by the IWRM concepts, and on the right side, a bottom-up approach, defined by water managers’ operational requirements.

The bottom-up approach requires exploring and understanding the working context and tasks achieved by water managers. To do so, elements of an answer can come from a different disciplinary perspective: Software engineering sciences. As software developers are often faced with domains they do not know (unlike hydrologist and

modellers in water management), they have developed methodologies and tools to understand the “real” tasks achieved by software users.

## **2.6. Software engineering sciences: formalising user participation**

Software design as used in computing and business sciences tends to adopt a “project” approach, emphasising task analyses and usability. Thus, Noguier (2005) describes the development of user-oriented software as involving the following steps:

- Evaluation of the existing context and constraints to clarify the general specifications of the project
- Analysis of working environment and tasks executed by end-users to build the conceptual software
- Validation of interfaces by using paper prototyping and user manual
- Development (programming) and distribution
- Surveys to collect user feed back to improve next versions of the software

Task analyses consist of collecting information on the way end users realise their activities for which the software is developed (Sebillotte, 1994). These analyses can be conducted using interviews to identify the intended task and through observing users to identify actual tasks achieved. Indeed, intended tasks described by users are often different from actual tasks (Noguier, 2005). To understand these tasks, software engineering sciences have developed a range of methods and tools enabling them to schematise and conceptualise the decision process undergone by users when achieving their tasks. The understanding of the knowledge, and especially the knowledge structure (Robillard, 1999), used by users to achieve their tasks can improve the development of software. Thus, Lee (2000:1178) states that:

*“A knowledge structure refers to a permanent structure of information stored in memory. The mental processing and representation of knowledge are complex activities, and hence various viewpoints and structures for capturing knowledge are necessary. Researchers in the cognitive sciences devoted a lot of effort to exploring many sorts of knowledge structures. Meanwhile, software engineers have developed methods, practices, and tools to ease the describing and processing of knowledge.”*

Some methodologies such as the Task Based Conceptual Graphs (Lee, 2000) are used as a framework to capture and organise the knowledge held within conceptual models. These conceptual graphs represent the structure of knowledge used to achieve user tasks and can then be transformed into executable programs.

Analyses of the working environment are also conducted through interviews and observation. These give developers more knowledge of users' computer skills as well as their ability to use applications. These analyses will influence the structure of the interface, the human/computer communication language as well as the possible need for training.

Writing the user manual and/or the paper prototype provides useful information to developers as they are forced to adopt user's points of view. The paper prototype of the interfaces can be described as the story line of the software showing the different interfaces with buttons, menus, etc. It is submitted and tested with users. Snyder (2003: 12) describes the advantages of paper prototyping as follows:

- Provides substantive user feedback early in the development process – before implementation
- Promotes rapid iterative development by experimenting various solutions before adopting one
- Facilitates communication within the development team and between the development team and customers
- Does not require any technical skills, so a multidisciplinary team can work together
- Encourages creativity in the product development process.

Nevertheless Snyder (2003) states as well that paper prototyping has its limitations and drawbacks concerning the difficulty to detect certain types of problems and might not always generate compelling benefits. Training and testing users with the software itself remains the best way of detecting human/computer dialogue problems.

Since the 1990s, software developers have developed and used the Unified Modelling Language (UML) for specifying, constructing, visualizing, and documenting the artifacts of a software-intensive system. UML was meant to be a unifying language enabling programmers to model computer applications. One reason UML has become a standard modelling language is that it is programming-language independent. Also, the UML notation set is a language and not a methodology. UML provides several types of diagrams that increase the ease of understanding and application under development. The most useful standard UML diagrams are: Use case diagram, class diagram, sequence diagram, statechart diagram, activity diagram, component diagram, and deployment diagram. These diagrams follow conventions and aim at assisting communication between developers and users as well as the translation of users requirements into programs. UML diagrams allow the visualization of the functional requirements of a system, including the relationship of "actors" (human beings who will interact with the system) to essential processes, as well as the relationships among the different entities (people, things, and data), the procedures, the tasks achieved by users or the link between the different components of the software (Bell, 2006).

Modellers and scientists from natural sciences backgrounds involved in developing DAs are focused on the modelling of a natural system. Software developers are more focused on the engineering role of software and have therefore generated a range of tools and methods to capture the requirements of users. Although the two sciences have been described separately, there have been attempts to learn from the other discipline. Loucks (1995) suggested the use of paper prototyping of visual interfaces - commonly used by software engineers - for the development of DAs. For example, the paper prototyping method was used for the development of the "AgET" DA. AgET is a decision aid illustrating the consequences of alternative cropping and grazing practices in terms of water unused by plants and flowing to the water table in Western Australia. Argent (2001) shows that the use of paper prototyping for the development of AgET was a success and resulted in the development of a DA that clearly reflected the needs of users. Nevertheless, it is not mentioned whether AgET was actually used by targeted users.

## **2.7. A development approach: implementation of project management to software engineering**

### **2.7.1. Origin and evolution of Project Management**

In the early 1950s the first public thoughts appeared about how to conduct a project, especially in English speaking countries. They were linked to big industrial projects such as aviation industry, public works and armament. The objective was to develop techniques and methods to improve the management of projects and the coordination of the various professions involved in projects. Historically, this development is part of operational research which intends to mathematically formalise management problems to take optimal decisions (Morley, 2008)

During the last thirty years, professional organisations from services and consulting companies have actively promoted the important role and skills of project leaders. Their activism has lead to a spread and recognition of project management certifications validating the acquisition of specific knowledge and expertise. There are different certifications agencies, such as the AFITEP (Francophone Project Management Association), the IPMA (International Project Management Association) and the PMI (Project Management Institute).

These certifications have greatly influenced the way projects have been conducted. The concept of project and the activities linked to project management have also been clearly defined. There are several definitions of the concept of project. A simple and accepted one is: is a finite endeavour - having specific start and completion dates-undertaken to meet particular goals and objectives (Nokes, 2007). A project can be represented using a triangle where corners represent production (objective), time (time frame) and resources (means) (Morley, 2008). This triangle expresses the solidarity constraint that exists between the corners. If one of the corners moves, it is necessary to change the other corners to keep the same triangle. Any evolution of the project perimeter will have consequences on the project timeframe or on the means to use. Managing a project consists of managing the three dimensions of a triangle.

### **2.7.2. Development of Information Systems**

An Information System is a set of organised resources such as equipment, software, staff, and processes which enable to collect, process, store and communicate information within organisations. A “project triangle” (see above) can be applied to an information system, as follows (Morley, 2008):

1. There are some interactions between objective and means on the one hand and time frame on the other hand. A first identification of the objective will allow a rough estimation of the project work load. This will enable to decide on a theoretical deadline and on the means that need to be allocated. If other constraints appear to limit time or budget, the objective has to be adjusted on the basis of the design-to-cost principle. Once decisions regarding the objective are taken, means and time frame can be considered as fixed. Any evaluation of the project will then be based on the basis of the means and time frame initially allocated.
2. An information system is not a tangible object and is difficult to be represented visually. Software is virtual and is described on the basis of functions. Models and prototypes only represent the software partially (unlike in industrial projects when a tangible object is produced).
3. The development of an information system happens within an organisation whose characteristics are part of the project itself.

The behaviour of actors is influenced by the organisational system within which they act. It entails the distribution of power and resources, the division of activities, the mode of coordination, the operational processes, etc. Relationships between actors are governed by a range of norms based on the main values of the organisation. Although power is often an issue in organisational systems, it is usually the efficiency that is put forward for design choices (cost, speed, etc.) concerning information systems. The rationale of an information system is usually guided by optimisation rationality without considering other forms of rationality. Although developing an information system is a rational process, it is usually part of a political process and a psychological process. This needs to be taken into account to analyse actors' behaviour or conflict (Malézieux et al., 2001).



### **2.7.3. Objectives of information systems**

It is important to distinguish information system and computer systems.

- The computer system is an organised set of technical objects which implementation is the infrastructure of the information system.
- The information system includes the information, the events and processes that impact the information and the actors that use or have an impact on the information.

Even if an information system project includes the development or the setting up of software, the objectives of the project are those of the information system. It is the use of the software (its help to the process and information processed) that will assist the organisation. The project objectives must therefore be in line with the strategy of the organisation. The role of the information system is to assist the organisation to reach its objectives. Therefore, an information system project is always part of an organisation's project. It implies that the expert, called project manager, takes decisions about the information system's evolutions. It means also that the strategic orientations of the organisation need to be translated into information system objectives, which must be part of the first phases of the project (Morley, 2008).

Understanding the objectives of the project and finding the appropriate responses is part of the project leader's responsibilities. The five most common categories of objectives are (summarised from Morley, 2008):

1. Administrative productivity: aims to get high returns on investments by reducing manpower through automation of some of the tasks. In this situation, there can be some difficulties to get users to participate because of social tensions linked to the automation which can hamper the realisation of the project.
2. Management Aid: Main objective of the project is to improve decision taking by providing a management information system. The design of this information system must be done with the decision makers otherwise the information system is less likely to be used.
3. Operational efficiency: For a better operational running, communication and information technologies to be used.

4. Progressive nature: The objective is to build a flexible system that can be modified quickly in case of an evolution of the constraints and the strategy of the organisation during the project.
5. Use of a new technology: The main objective is to experiment with a new technology, in order to assess it or to display it to the outside for its attractiveness.

This section has described the characteristics and the objectives of Information system projects, the next section describe in detail their management.

#### **2.7.4. Project division and development models**

According to the triangle metaphor, a key responsibility of a project leader is to divide the project in order to distribute the production and resources within time. Division, on the other hand, must aim to reduce the difficulties and take into account the links that exist between the various components of a project. Dividing a project consists of identifying sub-sets that are (almost) autonomous and present the following characteristics:

- Each sub-set leads to a specific output
- The workload of each sub-set can be assessed
- Some sub-sets can be realised in parallel while others need to be done one after the other.
- There are different scales of divisions and sub-sets are also often divided

There are two main criteria used to divide a project: The first one is linked to the time, the second one is related to the structure. The first criterion is used in most projects: It allows dividing projects according to the time necessary for each phase. Each phase is given a predicted start and end date. A project is composed of phases: Each phase entails a number of activities. An activity can be defined by one or more tasks to realise. The organised set of phases of a project is called the project life cycle. The temporal division of a project has two aims: To mark out and guide. Each date represents a milestone that enables identification of the points when decisions will be taken. Most information system design methods propose this kind of progression which is often called a development cycle. The temporal division is most of the time top-down and

favours an increasing visibility and a real progress of work if the consolidated results of a phase or activity are not questioned during the following phases (Morley, 2008).

The client and the project leader will benefit from the division of a project according to the time criteria. The temporal division allows the client to ensure that the outputs of the various phases follow the general objectives, take decisions and eventually give new orientations. The project leader gains from dividing the project as he can evaluate step by step the progress made.

The structural division allows organising the work based on the structure of the final product. Structural division presents a number of advantages:

- Control of the project: The division creates a number of subsets that are smaller in size and therefore easier to control
- Sharing responsibilities: If the various components of the projects are autonomous they can be realised as sub-projects in charge of different persons or companies
- Decrease the planned delays: When components are autonomous they can be realised in parallel
- Incremental development: For various reasons (size, budget, delays), Information Systems are sometimes developed in different versions, in this case the number of components included increases with each version.

The division depends on the different project components that need to be produced. It requires a good understanding and vision of the final product.

### **2.7.5. Information Systems (IS) and project life cycle**

The standard life cycle of a project is composed of four phases:

- Feasibility study
- Definition of solutions
- Detailed design
- Realisation

This type of standard division of a project, however, cannot be used as such for IS projects. Standard temporal division is especially difficult to implement for IS as it implies that the client will be able to present precisely what he expects. Defining the specifications of IS projects, i.e. determining needs and appropriate solutions, is a major challenge. There is often a progressive construction based on an iterative approach to allow the needs to emerge (Morley, 2008).

A single approach cannot be used for all projects. The temporal division has to take the project's and the company's characteristics into account. This can be achieved by relying on generic temporal divisions, called process models or life cycle models. The main existing life cycle models are: 1) code-and-fix model, 2) transform model, 3) waterfall model, 4) V model, 5) W model, 6) evolutionary design model, and 7) spiral model.

The code-and-fix model is appropriate when users' needs can be determined easily. After a brief phase focused on understanding the objectives, the IS can be developed. These two are often followed by tests realized with users to reach the targeted aim.

The transform model is adopted if specifications of the targeted IS can be transformed automatically into programs. For this model, most of the efforts aim to describe comprehensively the specifications and then validate them with users. This model requires a sequence of specifications/validations phases that ends up by the generation of codes.

The waterfall model can be opposed to the code and fix model. This model relies on a rigorous development process and on well defined roles of the developer and the client. In this case, the temporal division consists in a succession of phases organised in a descending manner. Each phase is officially controlled and validated and the next phase starts only when the result of the control is satisfactory. Otherwise, the product is modified to become satisfactory. There is no possibility of return to the validated options of the precedent phase.

The V model is an improved version of the waterfall model. This model was used for the development of RUBDAv2. It aims to reduce the "tunnel effect" of the waterfall

model were the client loses visibility on the project. The aim is to avoid the risk of having clients that discover a product at the end of the tunnel that is not as expected. That can be true even if the product complies with the specifications. This is due to the fact that it is often hard to transform users' expectations into specifications. Validating the documents is therefore not sufficient. The main advantage of the V model is that there is a real effort of anticipation made by the developers. The project members define during each phase the criteria that will be used at the end to evaluate and validate the work. It allows avoiding any surprise at the end of each phase and reducing the chances of having to rethink and redo any work.

The W model is an enriched version of the V model that follows the same aim: Anticipation of the final product. It adds another V phase before the one described in the V model that includes an assessment of the "raw" needs of the users and explores ways of reaching these needs by producing various prototypes. This allows running some experiments and evaluating the best options before starting the V model.

The evolutionary design model aims to build progressively the IS in a participatory manner. It lies on the principle that the needs of users can only be expressed through experiments, even at an early stage of the development, when the IS is incomplete or even rudimentary. The model is divided in phases, each phase ends up by producing a new version of the IS, the process stops when the client is satisfied by the product.

The spiral model is based on the same principles as the evolutionary model: User participation, but each phase is part of a contract between the developer and the client, where the commitments and validations are formalised. Each new "cycle" is preceded by the signature of a contract based on the needs identified during the preceding phases. Each cycle is composed of six steps: risk analysis, development of a prototype, simulations run with the prototype, identifications of the needs based on the simulations, validation of the needs by the steering committee, planning of the next cycle.

## **2.8. Conclusions**

The concept of IWRM, albeit somehow nebulous has played a key role in stimulating the development and application of Decision Aids or Decision Support Systems for water resource management. Studies show tensions between theory and practice, however, and highlight the existence of key barriers to the use of DAs. A large number of factors have been identified in the literature reasons to explain the non-use of DAs by policy makers and managers. These factors are linked to different parts and processes of the development of DAs, starting from the modelling *per se* to the design of the tool, including the involvement of users.

In response to these challenges, there has been growing interests in using ideas from software engineering and project management approaches in order to foster user participation in the development process. The involvement of users is formalised in project management through validation mechanisms that are meant to ensure that the software is developed as requested. Project management approaches applied to software engineering, here termed software project management, bounds developers to understand, analyse and develop software according to the clients' requests.

It is in this context of IWRM and growing interest in the use of project management approaches that the work of this thesis is situated. This study began by exploring the opportunity of developing a context-specific DA to implement IWRM and progressively incorporated user-specific requirements towards developing a fully operational DA.

## **Chapter 3 - Case study: The Upper Great Ruaha River Catchment in Tanzania**

This chapter describes the study area and the main challenges faced by water managers and water users in the area. The chapter demonstrates the difficulties that water managers of the Rufiji Basin Water Office face to achieve their mission and explains how this context and the associated challenges have led to the need for a water resources management DA.

### **3.1. Introduction**

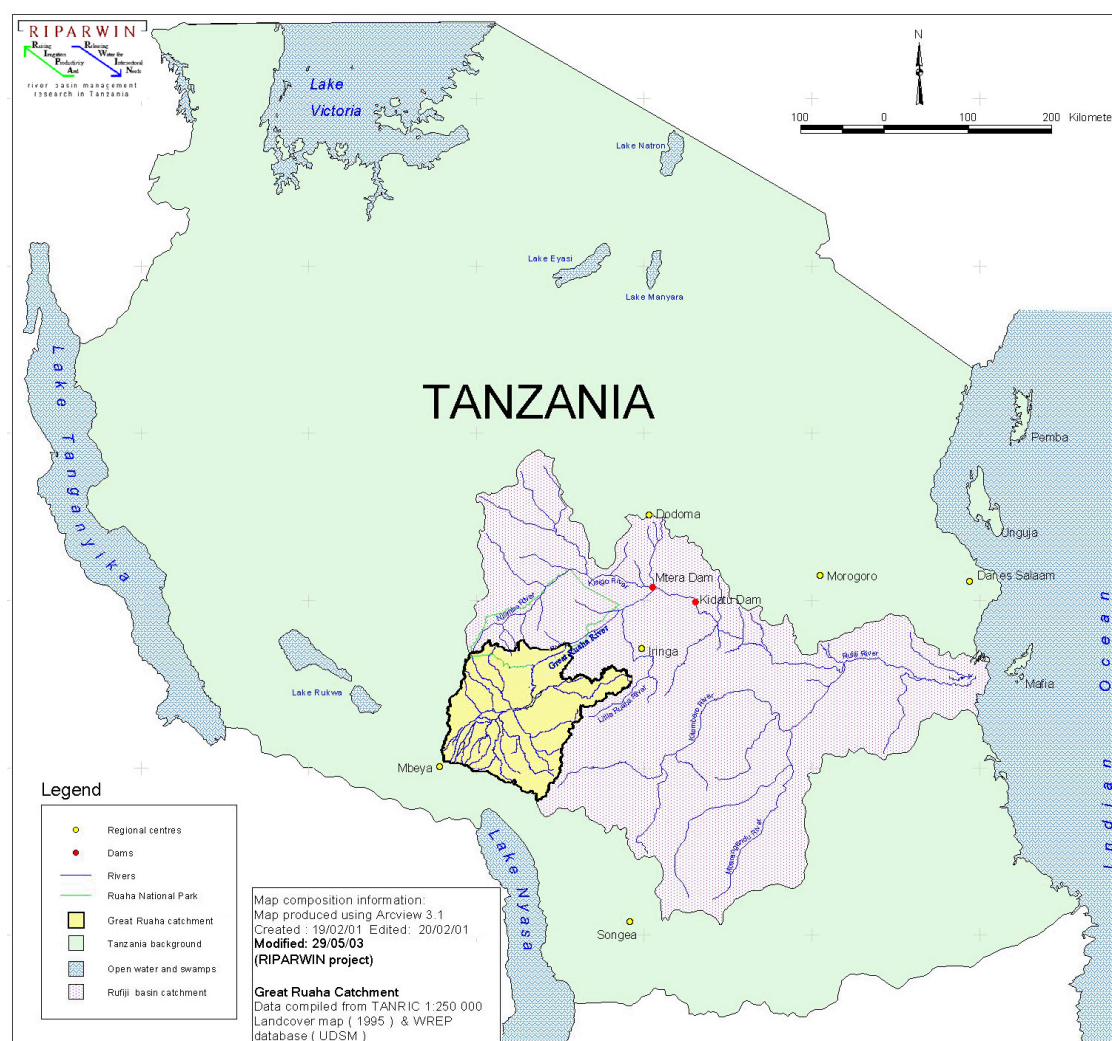
The Upper Great Ruaha River Catchment (UGRRC) is located in south-west Tanzania (Figure 7). It is a sub-catchment of the Rufiji Basin and has an area of 54 000 km<sup>2</sup>. It comprises multi-sectoral water uses that have different but important impacts on the livelihoods of the local people and on the national economy as a whole.

The UGRRC presents a number of favourable conditions for the implementation of a study about IWRM concepts and their implementation. For example, the catchment has been facing a water crisis for the last 15 years, with increasing competition between the various sectors over limited water resources. The organisations involved in managing water resources, like the Rufiji Basin Water Office and district councils, are therefore desperate to find solutions and expressed a need for tools to assist them in managing water resources. In addition, there was an opportunity in terms of financial and technical support for the development of a DA through the ongoing RIPARWIN (Raising Irrigation Productivity And Releasing Water for Intersectoral Needs) cooperation project.

The Rufiji basin drains the Tanzanian Southern Highlands into the Indian Ocean (see Figure 7). Various water uses co-exist in the basin, including domestic and livestock water supply, irrigation (mainly in the Great Ruaha and Kilombero valleys), hydro-power generation, fishing and wildlife water supply and transport. The basin comprises four major rivers: Great Ruaha, Kilombero, Luwengu and Rufiji. A number of studies have documented the water resource problems facing the basin (Baur et al 2000; World

Bank, 1997; and URT 1995). Water resources in the basin are mainly used for irrigation, generation of electricity, and domestic use. Competition is largely between downstream hydropower generation and upstream irrigation, due mainly to the design of hydropower schemes that did not take an increasing irrigation demand into account. There is also a perception that the situation is further aggravated by wastage of water, for nearly all abstractions by smallholder irrigators are not controlled nor are there incentives in place to encourage efficient water use (Maganga, 2002).

*Figure 7: Map showing the Rufiji River Basin and the Upper Great Ruaha River Catchment*



Water reforms in Tanzania have focused on the use of statutory legal systems to regulate the use of water resources. Yet Tanzania operates under a plural legal system, where diverse customary systems are relied upon for gaining access to and utilising water resources. It has been noted for Tanzania that “very few human activities are regulated by statutory laws alone, and neglect of customary laws may cause IWRM



implementation to fail, or will have negative consequences for individuals and groups who were better served by customary-based systems” (Maganga, 2002:1). In this chapter, therefore, after a short description of Tanzania and the geography of the UGRRC, the multiplicity of formal and informal institutions dealing with water resources management are described. Special attention is given to the Rufiji Basin Water Office, especially its role and the difficulties it faces to achieve its missions, as it is the main organisation targeted by the DA that was developed during this research.

### **3.2. The United Republic of Tanzania**

The United Republic of Tanzania, which comprises the mainland and the island of Zanzibar, has a total area of 945,090 km<sup>2</sup>. The country is located in the eastern part of Africa, and is bordered by Kenya and Uganda to the north, by the Indian Ocean to the east, by Mozambique to the south and by Rwanda, Burundi, the Democratic Republic of the Congo and Zambia to the west. Its present boundaries date back to 1964, when Tanganyika and Zanzibar were merged, shortly after independence. The country is part of the African Great Lake area and hosts some of the most beautiful and attractive National Parks of the Continent as well as other impressive tourist attractions.

Politically, Tanzania has remained fairly stable since its independence. During the 2005 presidential election, there was a fairly smooth transfer of power to Jakaya Kikwete after the ten-year rule of Benjamin Mkapa (the maximum allowed under the constitution). These elections were seen to be a step further towards the consolidation of democracy in Tanzania (although both politicians belong to the ruling party). Tanzania is strategically located as it belongs to both the East African Community and to the Southern African Development Community. This, combined with its relative stability, makes Tanzania an attractive country for donors. Partly as a result, Tanzania is highly dependant on foreign aid. The Development Gateway Foundation<sup>3</sup> recorded more than 4000 development projects achieved or on-going in Tanzania between 1999 and 2007,

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<sup>3</sup> Development Gateway is an international non profit organization measuring and providing tools that aims to make aid and development efforts more effective around the world (<http://www.dgfoundation.org/>) .

of which more than 200 concerned Water and Sanitation and more than 400 concerned agricultural development.

Tanzania has a total population of about 37.6 million (UNDP 2006), of which 76% live in rural areas where poverty is concentrated. Tanzania belongs to the countries classified as low human development countries, having the 162<sup>nd</sup> position among 177 in the UNDP Human Development Index (UNDP, 2006). Demographic pressure remains a high challenge for the development of the country, with a population growth rate of 1.7% (2004-2015 projection). Infant mortality rate is 78 per 1,000 live births and HIV prevalence is 6.5%. In 2004, approximately 31% of adults were illiterate and Tanzanians had a life expectancy of only 46 years, indicating that public services were insufficient (UNDP, 2006). In 2005, Tanzania had a GDP per capita of US\$700, with half of the GDP accounted for by agriculture, although industrial production and the extraction of gold and other minerals has increased in recent years.

Land cover is dominated by woodland, grassland and bushland which together account for about 80% of total land area. Cultivable area is estimated to be 40 million ha, or 42% of total land area. In 2002, just 13% of the cultivable area was actually cultivated, comprising 4 million ha of arable land and 1.1 million ha under permanent crops (UNDP, 2006). The agricultural sector continues to lead economic growth in spite of the recent emergence of the new high-growth sectors of mining and tourism, and continues to have the highest impact on the levels of overall economic growth. Agriculture provides work for 14.7 million people, or 79% of the total economically active population. Small-scale subsistence farmers comprise more than 90% of the farming population, with medium and large-scale farmers accounting for the remainder.

In recent years, Tanzania has not been self-sufficient in cereals, but is self-sufficient in non-cereals at the national level. However, there is a clear difference in the supply capabilities of staple-food crops among regions. The study area is one of Tanzania's most productive areas, and is one of the four regions that are self-sufficient and export cereals (mainly rice) to other regions of the country.

### **3.3. Institutional and legal reforms in Tanzania: towards IWRM**

Natural resources in Tanzania were governed by informal rules until the early 1900s when the German colonial government first started efforts to curb water problems as a response to increasing water demand (Sokile et al., 2003). The first Statutory Water Law (1923 Water Ordinance) as well as by-laws concerning water management were proclaimed in the 1920s. These state policies remained active until the 1960s when Tanzania adopted a socialist economy and launched the creation of a policy framework incorporating natural resource management into a broader national framework of sustainable social and economic development, which insisted upon the collective ownership of natural resources. In 1974, the Water Utilisation (Control and Regulation) Act (Principal Act No. 42 of 1974) was produced and became the main piece of water legislation in Tanzania. The Water Utilisation Act regulates the use of rivers, streams and internal lakes. It is a control and regulation law that declared all water to belong to the state and designated waters as National waters and Regional waters. This ultimate ownership of water enables the Republic to exert control over not only distribution and supply of water, but also prevention, reduction and control of pollution of waters. Direct abstraction of underground water is allowed under certain circumstances, as elaborated in the Water Utilisation Act.

The Tanzanian Government, prompted by increasing pressure on land and water resources, has been busy trying to establish formal legal systems, fixing property regimes and formalising informal arrangements in a bid to develop efficient and transparent institutional frameworks for the management of these resources. In 1981, the Ministry of Water amended the principal Act of 1974 to adopt a River Basin Management Approach for water resource management and divided the country into nine basins (Act No.10 of 1981). A “Water Basin” is defined as any area of land delimited and declared by the Minister to be a Water Basin in relation to any river or other water source under Section 7 of the 1974 Water Utilisation Act. The Regional Water Advisory Boards as defined under the Water Utilisation Act 1974 were renamed as Basin Water Boards under the amendment of 1981. The Basin Water Boards were to be established according to water basins declared by the Ministry of Water Development.

Basin Water Boards and Offices were created to manage water utilisation by different users. The Act furnishes an elaborate system of Water Rights, which is the means through which water abstractions, uses and diversions are brought under regulative regimes of law. Several conditions are read into every Water Right granted for mining, forestry, industrial purposes or power generation. As emphasised by Rajabu and Mahoo (2008: 3) “the effectiveness of water resource management and the application of the legal framework [in Tanzania], depend on the quality of water rights administration”.

In 1995, a comprehensive review of Tanzania’s water resource policies and institutions was carried out by the Government of Tanzania, World Bank and DANIDA (DANIDA & World Bank, 1995). On the basis of this review, an inter-ministerial project, entitled River Basin Management and Smallholder Irrigation Improvement Project (RBMSIIP), was launched in 1996. The objective of this project was to strengthen the government’s capacity to manage water resources and address water-related environmental concerns at the national level and in the Rufiji and Pangani River Basins, and to improve the irrigation efficiency of selected smallholder traditional irrigation schemes in these two basins (World Bank, 2004). RBMSIIP sought to achieve this through a stronger institutional, regulatory and incentive framework for basin management, and through enhanced stakeholder participation in irrigation scheme operation.

There were two main components:

- River basin management (RBM)
- Smallholder irrigation improvement project (SIIP).

The River Basin Management component of the project was hosted by the ministry responsible for water, while the Smallholder Irrigation Improvement Project component was lodged with the Ministry of Agriculture. The project aimed at increasing water productivity, and as an example, many water intakes were modernised under this objective.

In 2002, Tanzania formulated a new National Water Policy, which emphasised maximising the economic and social wellbeing generated by the development and use of water resources and ecosystems in such a way as to ensure that the present and future generations enjoy the benefits of this vital resource. The National Water Policy (URT,

2002) embodies the principles of decentralisation and subsidiarity of water supply management, whereby this should be devolved to the lowest appropriate level. The policy further states that all water abstractions and effluent discharges into water bodies should be subjected to a “water use permit” or “discharge permit”, to be issued for a specific duration. The goal of the National Water Policy (URT, 2002: 27-8) is to incorporate the following objectives into water resources development and management:

- A minimum water supply is guaranteed to all humans to maintain human health, and sufficient water is guaranteed to restore and maintain the health, services and functions of ecosystems
- Water for food security, energy production and other economic activities is readily available
- Water quality is maintained to meet agreed objectives and standards, and human actions do not impair the long-term availability of freshwater stocks; water resources management is financed and raw water priced to promote efficiency, sustainability and equity
- Integrated water resources management (IWRM) is instituted
- Effective and sustainable strategies are in place to address natural and man-made water resources problems
- Water resources planning and decision-making are participatory involving all users and stakeholders
- Water resources data are available and easily accessible to all and an effective infrastructure and information system is in place and operational
- Institutional mechanisms exist to resolve conflicts over water resources
- Adequate number of motivated and highly skilled professionals is available.

Tanzania is currently (2009) in the process of developing a new water resource law, together with new administrative and institutional frameworks for implementation. Under considerable support received from the international donor community, Tanzania is attempting to adopt and implement IWRM (World Bank, 2004). However, there has been no conclusive study so far showing that the IWRM paradigm is applicable in the specific Tanzanian context. Moreover, the Ruaha River Basin contains some

biophysical conditions, characteristically found in sub-Saharan Africa, which pose special risks for the application of IWRM (Carter, 1998; Lankford et al. 2005).

By 2005, when the RIPARWIN study finished, the National Water Policy's implementation was limited because the Water Regulation Act of 1974 had not been amended to take into account the planned changes. The new National Water Policy was translated into three separate draft legislations: The Water Resources Development Act, the Rural Water Supply Act and the Urban Water Supply Act. The draft Water Resources Development Act (URT, 2004) considers that there is a possible interface between the formal (water rights) and informal (local and customary) water use. Building a legal and institutional framework that manages to conciliate the formal (legal) and informal (customary) management systems is one of the main challenges faced by Tanzania. Indeed, managing water resources using solely the formal instruments (legal and technical) cannot be effective as water uses are still mainly ruled by the customary system. The task of water managers within these formal institutions appears therefore impossible as the legal means that are available will not have the expected impacts on the uses of water resources. As Mermet (1991) stresses, whatever water managers decide upon, water is actually managed by people and water users themselves. Water users in Tanzania (Maganga et al. 2002, Rajabu and mahoo, 2008, Sokile et al. 2002) mostly rely on informal institutions, traditional by-laws, norms and restrictions that were insufficiently considered when the legal and institutional reforms were conducted. In this context, the room for manoeuvring by river basin authorities to implement the objectives stated within the National Water Policy (which adopted most of the concepts promoted by IWRM) is therefore limited (as they do not control water uses). The authorities are in a situation where on the one hand the state and international injunction is strong to implement reforms, while on the other hand they have to rapidly respond to new demands, climate variability and other requests of water users with limited financial, human and technical resources. To achieve their tasks, water managers such as the Basin Water Officers aim to progressively reinforce the formal institutions by incorporating the informal ones as control, monitoring and conflict prevention instruments at the local level. The formal and informal systems and their inter-linkages at the different scales of management are rightly described by Rajabu and Mahoo (2008):

*“Both formal and customary (or informal) water rights are currently in use in Tanzania. At the national level, water management is predominantly governed by the formal institutions, mainly policies, acts, legislations and related organisations that are judiciously established in accordance with the formal provisions. At the basin level, there is a mix of formal and informal arrangements, but the formal predominates, partly due to the fact that informal arrangements are often still quite localized and do not encompass the whole basin as yet. At the catchment and sub catchment levels, informal institutions and arrangements gain more strength.” (Rajabu and Mahoo, 2008:3)*

The complex interweaving of the formal and informal water management systems is described in detail in section 3.5.2 using the case study area as an example.

### **3.4. The Great Ruaha River Catchment**

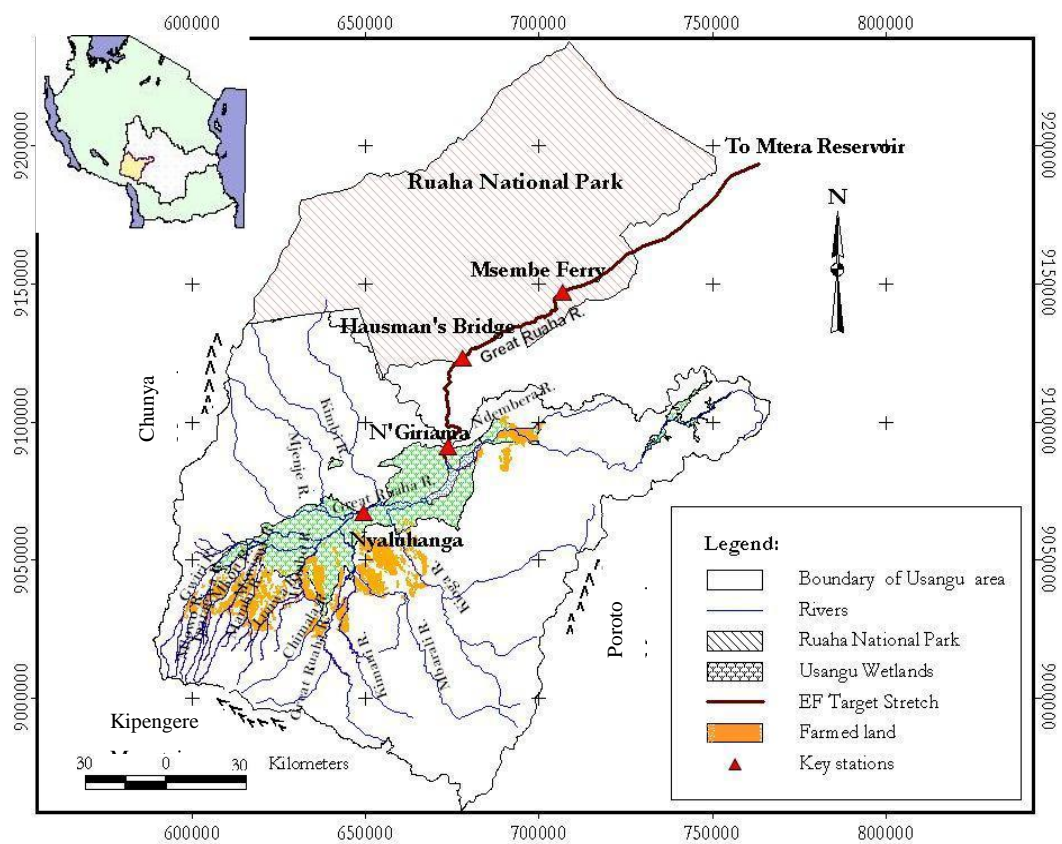
#### **3.4.1. Overview**

The Rufiji River Basin is the largest of the nine river basins in Tanzania, draining a total area of about 177,420 km<sup>2</sup> (URT, 1995) from the Southern Highlands into the Indian Ocean. The basin comprises four major rivers: the Great Ruaha, Kilombero, Luwengu and Rufiji. The Great Ruaha River drains an area of about 83,979km<sup>2</sup>. The study area is the upper part (above Msembe Ferry gauging station) of the Great Ruaha River Catchment (UGRRC), and covers an area of approximately 54,000 km<sup>2</sup>.

The Great Ruaha River originates from a number of large and small streams on the northern slopes of the Poroto and Kipengere Mountains in the Southern Highlands between Mbeya and Iringa. The river flows to the plains (called *Usangu* Plains) where several other rivers flowing from the highlands join it. Apart from these southern tributaries, the major tributaries of the Great Ruaha River include the Kisigo River, Little Ruaha, Lukosi and Yovi Rivers. The Great Ruaha River spills onto the Usangu Plains, forming the Usangu Wetlands (Western-Utengule and Eastern-Utengule) and feeding a perennial swamp (*Ihefu*) within the Eastern Wetland. It then flows through Ng’iriama (an exit to the Eastern Wetland) to the Ruaha National Park providing the

main water source to the park, and to the Mtera Dam, Tanzania's main electricity generation source, accounting for 56% of the runoff to Mtera Dam. As it flows down, it is joined by the Little Ruaha River before being joined by the Kisigo River. It then passes through the Mtera reservoir, before flowing eastward to the Kidatu reservoir, being joined on the way by the Lukosi and Yovi Rivers. From the Kidatu reservoir, it flows into the Kilombero Plains before joining the Rufiji River (just above Steigler's Gorge).

Figure 8: Map showing location of the study area: the UGRRC



Various water uses co-exist in the Rufiji River Basin, including domestic and livestock water supply, irrigation (mainly in the Great Ruaha and Kilombero valleys), hydro-power generation, fishing and wildlife water supply, and transport. A number of studies have documented the water resource problems facing the basin (Baur et al 2000; World Bank, 1997; URT, 1995).



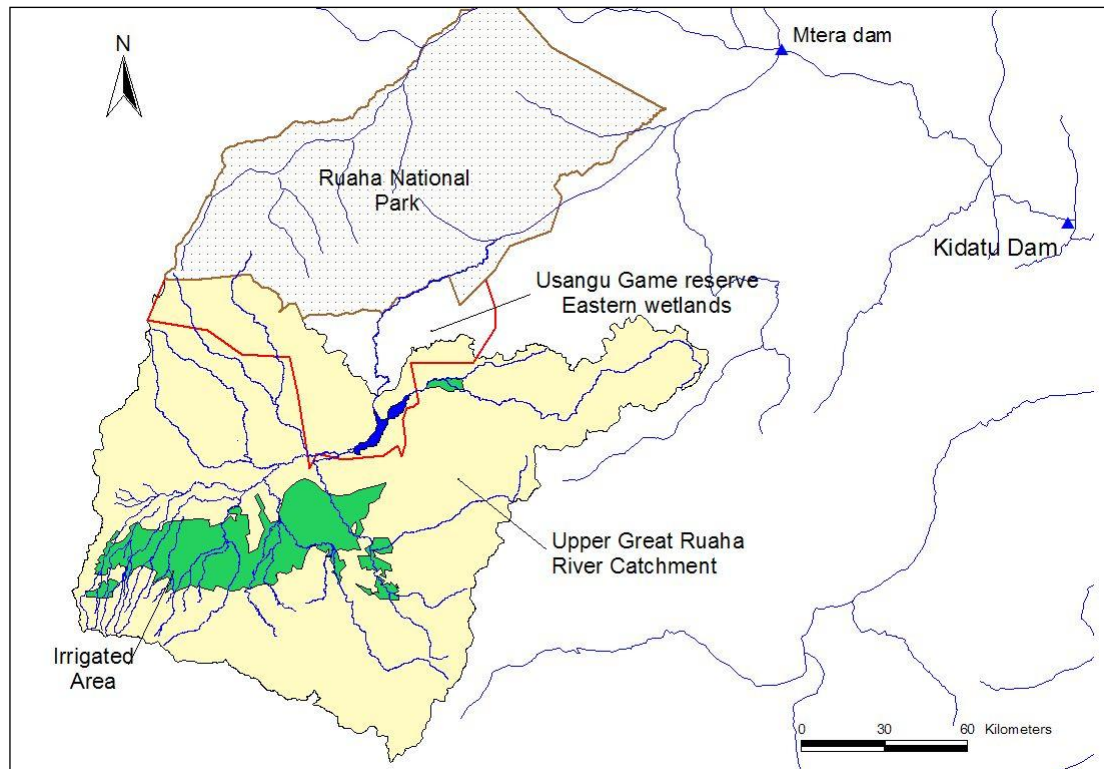
As noted in Maganga et al. (2002), within the Rufiji Basin the greatest water use occurs in the Great Ruaha sub-catchment, which is already experiencing water shortages and water use conflicts. Competition occurs mainly between downstream hydropower generation and upstream irrigation, due mainly to the design of hydropower schemes that did not take increasing irrigation demand into account. The situation has been further aggravated by wastage of water, as nearly all abstractions by smallholder irrigators are neither controlled, nor are incentives in place to encourage efficient water use.

In the UGRRC the rainfall regime is unimodal with a single rainy season (December to June). However, rainfall is highly localised and spatially varied. The mean annual rainfall varies from about 1,600 mm in the mountains and between 500 to 700 mm on the plains (Kashaigili, 2006). Likewise, the mean annual temperature varies from 18°C to 28°C from the mountains to the plains respectively. The mean annual potential evapotranspiration is 1,900 mm (SMUWC, 2001a). The vegetation in the mountains is constituted of humid forests and afro-alpine vegetation (above 2000m asl) and of *Miombo* woodland (between 2000 and 1100 m asl). In the plains, there are two different types of vegetation covering the fans and the wetlands. The fans are alluvial deposits (where most of the agriculture takes place) spreading from the mountains into the plains. The wetlands, located below the fans, comprise the western seasonal wetland (also called Western Floodplain) and the Eastern Wetlands. The eastern and western parts of the wetlands are joined by a narrow band of land along the Great Ruaha River. The Eastern Wetland entails a perennial swamp (Ihefu) and seasonally flooded grassland.

The Usangu Plains are drained by the Great Ruaha River: the major tributaries to the Great Ruaha River are the Mbarali, Kimani, Chimala and Ndembera Rivers (Figure 8). The rivers have their sources in the highest parts of the mountains and account for 85 % of the total discharge (SMUWC, 2001a). Smaller tributaries are the seasonal rivers that have their sources located in the lowest rainfall areas; such as the Umrobo, Mkoji, Lunwa, Mlomboji, Ipatagwa, Mambi, Kioga, Mjenje, Kimbi, Itambo and Mswiswi Rivers. The Great Ruaha River is the major supplier to the Eastern Wetlands but the Ndembera River also has significant inflows into the wetlands. The Eastern Wetlands are limited by a rock outcrop which acts as a natural dam controlling the outflows at

N’Giriama. Downstream of the Eastern Wetlands, the Great Ruaha River flows through the Ruaha National Park before flowing to the Mtera hydropower reservoir (Figure 9). The long term (i.e., 1958-2004) mean annual runoff (MAR) for the catchment up to Msembe Ferry gauging station, located in the Ruaha National Park (80 km downstream of N’Giriama), is  $77.4 \text{ m}^3\text{s}^{-1}$  (Kashaigili et al., 2006).

*Figure 9: Irrigated areas in the Upper Great Ruaha River Catchment*



For conservation interests, the Eastern Wetlands “are one of the most valuable freshwater ecosystems in Tanzania (...) home to over 400 different types of bird species and numerous other flora and fauna” (Kashaigili & al., 2006:3). In 1998, the Eastern Wetlands were gazetted as the Usangu Game Reserve. Before its gazettement, the Eastern Wetland supported various socio-economic activities (e.g. fishing, collection of medicinal plants and cattle grazing). It also had cultural importance and was used as a site for ritual prayers (Kashaigili, 2003). In recent decades, in part because of the various benefits derived from the wetlands, many ethnic groups have migrated to the Usangu Plains from other parts of Tanzania. These groups include pastoralists from Mwanza, Shinyanga, Tabora, as well as farmers and business people from other

neighbouring regions. Some people have also moved to the region from outside the country (i.e., from Europe and Asia) (SMUWC, 2001a).

### 3.4.2. Multiple water uses

The UGRRC comprises multi-sectoral water uses (Table 4) that have different but important impacts on the livelihoods of local people and on the national economy as a whole. Most of the basin's population depend on irrigation and other water-related activities (such as fishing and livestock keeping) to sustain their livelihoods. The comparison between population increase and irrigated area (Figure 8) shows the close relationship between the two parameters. The UGRRC, especially the fans, is characterised by a high concentration of traditional as well as improved irrigation systems. Irrigated paddy rice is the main water use, mainly practiced during the wet season in the alluvial plains, upstream of the Western Wetland. Water is diverted from both perennial and seasonal rivers. Irrigation here comprises large improved irrigation systems (covering approximately 6,200 ha) as well as smallholder irrigation, comprising both formal schemes and informal systems (covering approximately 37,000 ha). It is estimated that approximately 30,000 households are involved in irrigated agriculture.

Table 5: Water use in different sectors (Kashaigili & al. 2006)

Sector	Water use in the Upper Great Ruaha River Basin	
	Wet season (December to June)	Dry season (July to November)
	(x10 <sup>6</sup> m <sup>3</sup> )	(x10 <sup>6</sup> m <sup>3</sup> )
Irrigation	775.6	24.3
Livestock	8.2	19.6
Brick-making	-	0.2
Domestic	2.6	3.5
<b>TOTAL</b>	<b>786.4</b>	<b>47.6</b>
Hydropower, downstream	Annual value = 4096.3*	

Source of data: RIPARWIN (2005) Water productivity studies

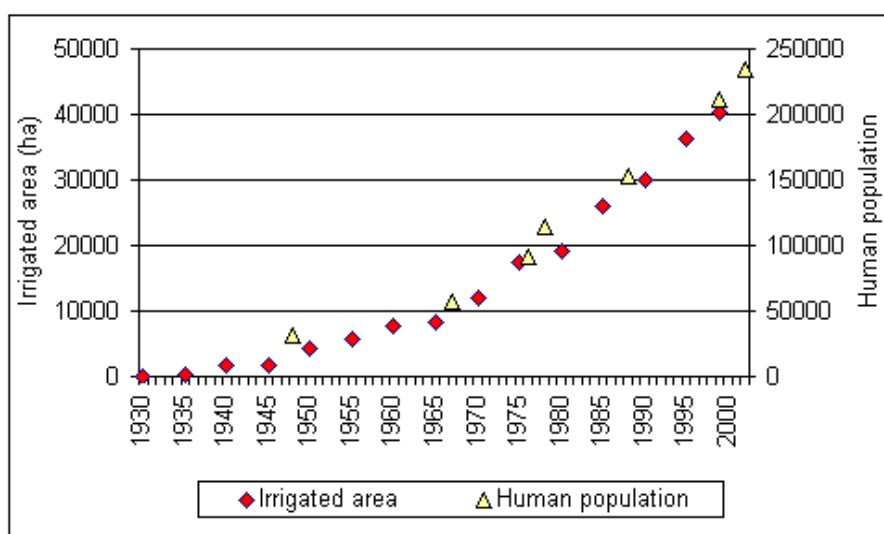
\* Hydropower is a long way downstream (see Figure 9) of the Usangu Plains. The figure incorporates turbine discharge plus evaporation losses from reservoirs.

Dry season irrigation (for high value crops such as vegetables) only occurs in localised areas in the upper courses of the rivers, and is an important means of livelihood. Yet the canals of these irrigation schemes also abstract water to meet other needs (e.g., domestic

uses and dry season activities such as brick making). Therefore, this is an area of high competitive water demand and persistent water conflicts. By contrast, in the lower parts of the plains, there is a low population density and a high concentration of livestock, especially cattle.

Besides downstream hydropower, which only consumes water through dam evaporation losses, irrigation is by far the largest water user. From 1970 to 2002, the irrigated area increased from approximately 10,000 to about 44,000 ha (SMUWC, 2001 b). However, the area varies from year to year depending on rainfall: in low rainfall years it may be as little as 20,000-24,000 ha (SMUWC, 2001b). Dry season irrigation is much less than wet season irrigation and covers only an estimated 2,500 ha (SMUWC, 2001b).

Figure 10: Changes in population and the area under irrigation in the UGRRC plains (1930-2005) (Kashaigili & al. 2006)



Source: SMUWC (2001b), Hazelwood and Livingstone (1978), Frank et al., 2004, Tanzania National Bureau of statistics – population census .

### 3.4.3. Water scarcity

The dry season is a water scarce period associated with conflicts and disputes over access to water. During this period, villagers along the rivers downstream of irrigated areas divert water for various uses including domestic supply, irrigation and brick-making. Increasingly, farmers have attempted to plant rice before the start of the wet

season in order to sell the produced crop as early as possible when prices are still high. According to Kashaigili et al. (2006), there are also large quantities of water that are simply discharged into non-productive fields and plots. Due to these abstractions, most downstream rivers that supply the wetlands have very minimal flows or cease to flow during the dry season. This has resulted in the transformation of the Western Wetland from a permanent to seasonal wetland, and a diminishing amount of water being supplied to the Eastern Wetland. Below the wetlands, the Great Ruaha River has been drying up completely during parts of the dry season since 1994.

*Table 6: Periods of zero flow in the Great Ruaha River (1994-2004) (Kashaigili & al. 2006).*

Year	Date flow stopped	Date flow resumed	Period of no flow (days)
1994	17 November	15 December	28
1995	19 October	23 December	65
1996	17 October	16 December	60
1997	20 September	22 November	63
1998	18 November	9 March 1999*	87
1999	21 September	20 December	90
2000	17 September	22 November	66
2001	12 November	23 December	41
2002	2 November	24 December	52
2003	21 September	16 January 2004*	104
2004	3 November	4 December	31

NOTE: \* with some intermediate start and stop to flow

Source: Sue Stolberger's records at Jongomero Camp in the Ruaha National Park (UTM: 679147E 9127828N)

Outflows of the wetlands cease when water-levels in the Eastern Wetland drop below the crest of the rock outcrop. Historically, flows at Msembe Ferry at the end of the dry season were typically between  $1 \text{ m}^3 \text{ s}^{-1}$  and  $3 \text{ m}^3 \text{ s}^{-1}$  (SMUWC, 2001b). Table 6 shows the periods of zero flows observed at the Jongomero Camp in the Ruaha National Park. Since 1994, the Ruaha River has been drying up every year. The river even dried up in the dry season of 1997, although there had been high rainfall in the previous wet season, associated with the El Niño phenomenon (Kashaigili & al., 2006: 6).

As the Great Ruaha River is the major source of water for the park, supplying about 80% of the total water, this has caused significant ecological change of both aquatic and terrestrial ecosystems in the park. In 2003, for example, about 5,000 fishes and 49 hippopotamuses died when the Great Ruaha River dried up (Ng'umbi, 2004).

### **3.5. Water resources management in the Upper Great Ruaha River Catchment**

#### **3.5.1. Political stakes**

The management of water resources in the UGRRC is of high importance in Tanzania. Indeed, as we have seen earlier, the UGRRC is the scene of several highly political stakes because:

1. It is a major rice production area in Tanzania, upon which the country relies to supply its national demand for rice and more generally to ensure its food security.
2. It supplies one of the major hydropower dams in Tanzania (in times when power cuts have become a threat to the development of the country and a major concern for public opinion).
3. It hosts one of the major wetlands of Tanzania: The Ramsar Convention on Wetlands was signed on 13<sup>th</sup> August 2000, binding Tanzania to the “conservation and wise use” of all wetlands.

Beyond the “technical” challenges faced by “water managers”, the management of water resources in the UGRRC became a political issue when the Ministry of Agriculture announced in 2002 that irrigated areas in Tanzania had to be doubled. The Government of Tanzania then committed itself to ensure that the Great Ruaha River would have a “year-round flow by 2010”, so to maintain river flows through the Ruaha National Park (Prime Minister, Mr. Frederick Sumaye, speaking at the Rio+10 preparatory meeting in London). Beyond these political appeals to ensure that certain sectors are prioritised (agriculture versus environment), water managers in the UGRRC were also in charge of implementing IWRM, adopted with the 1981 amendment to the Water Utilisation Act and with the National Water Policy of 2002. The National Water

Policy also established the environment as the second priority in the allocation of water, behind basic human needs.

Furthermore, the government committed itself to “integrated comprehensive approaches towards resources planning, development and management so that human activity does not endanger the sustenance of the Great Ruaha ecosystems” (Guardian newspaper (Tanzanian daily), 8<sup>th</sup> November 2001). This seems to mean ensuring sufficient water to sustain both the wetlands and the Ruaha National Park.

### **3.5.2. A struggle between informal and formal management**

In Tanzania, the legal and regulatory framework of water management is a mix of written ordinances that were made by the Legislative Council before independence as well as contemporary legislation, and the set of local, community-based practices that are normally determined by local customs, traditions and culture of the water users (Sokile et al. 2003, Maganga et al, 2002, Sokile & van Koppen, 2004, Sokile et al. 2005). Successive reforms of the legal and institutional system in Tanzania have focused on the use of the statutory legal system to regulate the use of water management, neglecting customary laws and practices. “At the national level, water management is predominantly governed by formal institutions, mainly policies, acts and legislations, and related organizations that are judiciously established in accordance with the formal provisions” (Sokile et al. 2005). At the local level, both formal and informal arrangements coexist, but informal arrangements prevail. Because these customary arrangements do not concern entire sub-catchments, and in order to define manageable units that allow the national and basin level authorities to manage water with their limited financial and technical means, a “new” scale of management, the sub-catchment level, appeared. The aim of using the sub-catchment level as a management unit is to create a framework to articulate both the formal and informal systems. The institutions involved in the management of water resources in the UGRRC at the different management levels are as follows:

### ***National level***

Although the thrust of current water resource management in Tanzania is to implement water management at the basin level, the central ministerial level continues to play a significant role in water management and the coordination of all nine basins in the country. The main Ministries involved in the management of water resources are the following:

- Ministry of Water and Livestock Development, in charge of water supply through regional water engineers
- Ministry of Agriculture and Food Security, responsible for irrigation
- Hydropower, under the Tanzania Electric Supply Company (TANESCO) in the Ministry of Energy and Minerals
- Ministry of Natural Resources and Tourism, responsible for the conservation of biodiversity in water bodies
- Planning Authorities, which oversee the construction of resort facilities and hotels along the shorelines of lakes, rivers, islands and oceans
- Ministry of Industry and Commerce, responsible for industrial discharges to water.

The central level is responsible for developing, disseminating, monitoring and evaluating the National Water Policy 2002 (URT, 2002). The Water Utilisation Act of 1974, as amended, declares that all water is vested in the United Republic of Tanzania, sets conditions on the use of water, and authorises the Principal Water Officer, with statutory authority, to be responsible for setting policy and allocating water rights at a “national” level. The Central Water Board advises the Principal Water Officer to designate to each river basin their own water officer; and the above mentioned responsibilities are delegated to these River Basin Water Officers.

### ***River basin level: the Rufiji Basin Water Offices***

As with the national ministerial level, the basin level is dominated by formal institutions, with few informal arrangements. The UGRRC is part of the Rufiji Basin and is formally managed by the Rufiji Basin Water Office (RBWO). The RBWO and



the Rufiji Basin Water Board were set-up according to Act No.10 of 1981. The Basin Water Board is the principal advisory organ in matters relating to the utilisation of water and regulation of pollution. It was established to become an important water management and pollution control structure. A Basin Water Board is composed of seven to ten members appointed by the Ministry of Water and Livestock Development. The Board advises the Basin Water Office on all matters concerning the appointment of regional water supplies, the determination or modification of Water Rights, and on measures to be taken in cases of drought. Basin Water Boards have the power to carry out research and investigations into the causes of water pollution, and into ways for the efficient prevention or control of such pollution.

The main objectives of river basin water offices are firstly to act as principal executors of the Water Utilisation Act No. 42 of 1974, and its subsequent amendments (namely of 1981, 1989 and 1997) on water allocation and water pollution. Their next objective is to carry out research pertaining to water resources management. The specific objectives are to:

- Allocate and regulate pre-existing and new water rights within the basin
- Monitor water availability, water quality and water uses in the basin
- Control water pollution
- Collect the water user fees as per water law and regulations
- Mediate and resolve water conflicts within the basin
- Establish Water Users' Associations as per Act No. 42 of 1974.

Multiple management responsibilities are given to the basin level institutions. The main tasks that need to be achieved by the Rufiji Basin Water Office are:

- Lead the procedure for granting water rights (see Box 2)
- Create and update the water rights and water abstractions register,
- Establish and maintain a water resources data bank
- Raise the communities' social and political will and commitment towards water resources management problems
- Involve stakeholders in water resources management issues
- Establish Water Users' Associations as legal institutions linking the Office with stakeholders in all matters related to the management of water resources

- Water pollution monitoring and control and water apportioning in the basin
- Water resources monitoring
- Environmental and water resources management issues facilitation in the basin.

**Box 2. Procedure for granting formal water rights in Tanzania (from Rajabu 2008)**

« A person who requires to be a water user applies to the appropriate Basin Water Officer (BWO) through an application form. The form is then submitted to the BWO together with an appropriate application fee (current fee is USD 32). The BWO acknowledges receipt of the application forms and the application fee in writing and enters the application in a register and opens a file of it.

The BWO requests for information on the said application from people and experts who can provide information regarding the matters pertaining to the nature of application. Some of the people who are most commonly contacted are: District Executive Director (on current and customary rights); District Administrative Secretary (on any issues of concern, such as conflicts); and the District Agricultural and Livestock Development Officer (for estimation of water requirements and technical agricultural report).

In most large water use projects the applicant is asked to submit an Environmental Impact Assessment (EIA) Study Report to the Basin Water Board.

The BWO then submits the application to the Principal Water Officer for information and for announcement in the Government Gazette. The application will also be displayed at the District Commissioner's office of the district in which the right, if granted, will be exercised. The process of publishing the application in order to receive objections (if any) from the wider public is scheduled to take 40 days.

After the BWO has received the requested information, and if there are no objections from the relevant parties, the application will be taken to the Basin Water Board for discussion. The Board will advise the BWO on steps to take. The BWO then offers a Provisional Water Right Grant to last for a year.

The Provisional Grant allows the applicant to start construction work. In case of users who already have an intake that encompasses a "basic" structure, but is able (if operated properly) of allowing some water to flow down the river and drainage water to be safely returned to the river, the Provisional Grant allows them to undertake improvements of the irrigation infrastructures as well as to abstract water. If the works are not completed in the prescribed time the applicant will ask for an extension of time. After completion, the works are inspected by the relevant BWO.

If the works are satisfactory, the Basin Water Officer issues a Final Water Right Grant. If any of the consulted experts or others from the public object, the applicant is asked to respond in writing. After evaluating the objections and the applicant responses, the BWO asks the parties to appear in person and make their case. If an agreement is reached, the application is forwarded to the Basin Water Board (BWB) for approval. If the BWO fails to secure such an agreement, both the applicant and the objector(s) make their case to the BWB members under oath. The BWB makes a decision to grant/deny based on a majority rule. If any of the parties are not satisfied by the Board's decision, they have the right to appeal to the Minister for Water, whose decision is final and binding. » Rajabu (2008: 6,7)

Considering the lack of technical and financial resources available for the RBWO to execute all its stated tasks, the office mainly depends on pre-existing institutions and its capacity to involve local communities; especially for the regulation of river water flows in dry season, the collection of water user fees, and the mediation and resolution of water conflicts.

As noted in Maganga et al. (2001), farmers in Rufiji Basin view formal basin management suspiciously and consider these as efforts to safeguard TANESCO's interests in reserving sufficient water for hydropower (WORLD BANK, 1997). This negative perception is reinforced by the fact that TANESCO is providing most of the financial and material support for managing water resources in the basin – creating an impression of inequitable use of water resources and inequitable sharing of benefits derived from using the basin water resources Maganga et al. (2001).

The other main water management institutions in the basin are:

- The Zonal Irrigation Unit – Mbeya
- The Rufiji Basin Development Authority (RUBADA) which is in charge of promoting development in the basin, including measures of flood control, catchment conservation, and the building and maintaining of works for the collection, diversion and storage of water in the basin
- The Ministry of Agriculture and Food Security, through its extension agents and other activities

- NGOs, community-based organisations and grassroots organisations.

The water management institutions in the basin thus reflect the wider framework of the national level. Several government organisations and formal institutions are dominant, although such institutions do not presently guide day-to-day human interactions with water. Most of these institutions, especially the governmental ones, are normally backed by formal rules and constraints, whereas the village-based, local informal institutions are inconspicuous and often ignored. NGOs, although they are very influential in water management and service delivery (Sokile et al., 2002), are not fully involved in national or regional strategic management.

The Water Utilisation Act No.42 of 1974 (Control and Regulation) created Water Users' Associations (WUAs), now viewed as important conflict resolution tools which seek to reduce the number of water rights holders for the purpose of effectively coordinating water use. Currently, unregistered users abstracting water in accordance with customary law are being encouraged to regularise their water abstractions by forming WUAs.

However, formal water users' associations often have few linkages with informal associations of water users. WUAs and informal associations function very differently. In WUAs, users attend meetings, pay membership fees and apply for registration, whereas informal associations simply require users to have a stake in the water use. There is therefore a strong chance that WUAs remain disconnected from pre-existing informal ways of local water management, which can strongly weaken the effectiveness of WUAs (Sokile et al. 2005).

Additionally, several initiatives were undertaken in the basin during the last 10 years, such as the gazettement of the Ihefu Wetland as a Game Reserve in 1998 by the Ministry of Natural Resources. People that were depending on the wetlands for livestock keeping, agriculture, fishing and bee keeping found that they were no longer allowed to utilise the resources in the reserve. The gazettement, which has left a large population without real alternatives, is one of several initiatives undertaken by decision-makers without reference to other Ministries or initiatives. This gazettement lacked

initial coordination between managing organisations, while it appears to have had little success in restoring downstream flows.

### ***Local level: The ward, village and below***

One of the main challenges faced by the RBWO lies in finding a legitimacy as well as ways of exercising its mandates at the local level. It is by interacting with these institutions that the RBWO can effectively manage water resources. Understanding the institutional framework that exists at the local level is thus important to understand the challenges faced by the RBWO but as well to understand the needs of its managers and the context within which the DA had to be applied.

At the local level the formal institutions are district councils, wards and villages. Wards comprise three to seven villages, and play an important role in water management. “The Ward Development Committees frequently pass by-laws that impact on sanctions and penalties that seek to guide water allocation and quality” (Sokile et al, 2005). Each ward’s community members elect a Ward Councillor, who can have a great influence in water resources management. “Councillors can for example, mobilise downstream water users for negotiating for water upstream, mobilise funds for domestic water supply, push by-laws for water management at the District Council, and mobilise communities towards the formation of WUAs” (Sokile et al, 2005). Ward Councillors can therefore be a link between formal and informal institutions.

The Water Utilisation (Control and Regulation) Act 1974 created a novelty in the form of WUAs, which are an important conflict resolution tool for water management. The associations whose formation has been going on for several decades now, seek to reduce the number of Water Rights holders so to effectively supervise water use, thus transforming the various committees and village user groups (ruled by customary arrangements). A WUA with a Water Right has obligations like any other Water Right holder.

Districts, wards and villages can make decisions about water management. However so can the sub-office of the RBWO at Rujewa, the main town in Mbarali District. This sub-office’s main task is to coordinate water management through WUAs and through

village committees in cases where there are no WUAs. This sub-office has occasionally used community leaders for water management activities implementation, and this collaboration has been very fruitful.

The village is the lowest level of formal institutions. Informal arrangements for water management are at the village-level most elaborate, and there are many links between formal and informal initiatives. Elected Village Councils have the responsibilities for handling daily affairs, and act through the following three committees: Finance, Economic and Planning Committee; Social Services and Self-reliance Committee, and Law and Order Committee. The Social Services and Self-reliance Committees have water sub-committees (Sokile & Mwaluvanda, 2005).

The functioning of sub-committees largely depends upon specific situations. In places with little irrigation, informal arrangements through customs and traditional rainmakers are more popular. However, where irrigation is highly practiced, there is an active formal WUA which handles both domestic and irrigation water management.

In the UGGRC, there are villagers that organised themselves through an informal association in order to construct an irrigation system. Maganga (2002) uses the Nyeregete village as a good example of the informal types of arrangements existing in the UGRRC (see Box 2). In 1964, a small group of villages from the Nyeregete village dug a canal for irrigation as a complementary source of water for their farms because of the erratic rainfall. Villagers had to organise themselves to build the canal and Maganga (2002: 5) explains that to do so the “villagers were influenced by indigenous knowledge and customs related to water use in the area”.

As noted by Maganga (2002:6) “there is a lot of resentment among the local people about attempts by newly-created Rufiji Water Board to assert its authority regarding water allocation” in the UGRRC. Maganga (2002) further states that the villagers did not understand why there were asked to pay for the water right when they had to register their irrigation canal as it was asked by the Rufiji Basin Water Board.

**Box 3: The Nyeregete canal committee Maganga (2002)**

“The Nyeregete canal was therefore constructed by referring to the customary system of obtaining irrigation water, where people organise themselves informally and construct a canal to divert water from Kiyoga river. Each member of the canal then constructed smaller furrows to tap water from the main canal to their fields. Such canal groups may be initiated by a single individual, and afterwards it may grow into a larger Canal Committee, such as the one in Nyeregete, which, according to informants, has a membership of 100 and it covers a distance of about 20 miles. The Canal Committees and sub-committees (established for each subcanal) oversee the allocation of water to members, as well as the maintenance of the canal. The Nyeregete Canal has to be cleaned every year during the months of August-December, and if a member abstains from the maintenance activities, he or she is liable to a fine.

Irrigation has made it possible for Nyeregete villagers to introduce an important cash crop, rice, a feat they could never hope to achieve without the construction of the canal. With the income accruing from irrigated rice some villagers can now buy the maize they need for food instead of trying to raise it themselves (maize does not do very well in Nyeregete).” Maganga (2002:5-6)

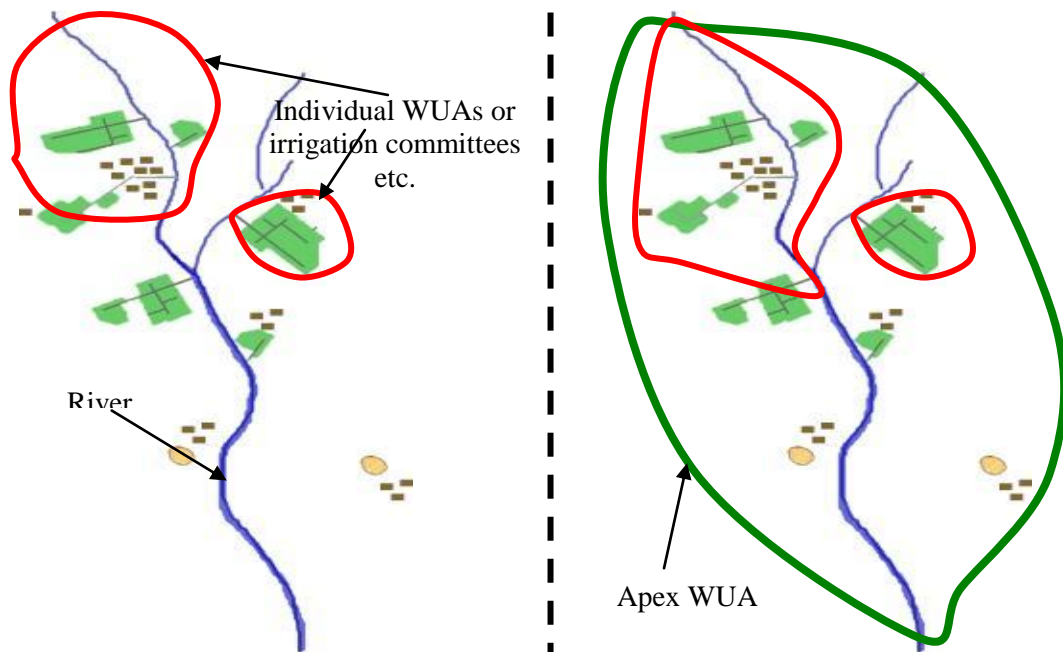
The above example of Nyeregete lends weight to the observation by Sokile et al. (2003) that “[t]he present institutional framework ignores informal institutions, especially traditional by-laws, norms and restrictions” (Sokile et al., 2003). The predominance of isolated institutions locked into narrowly defined activities, with no interactive learning, is likely to continue to hamper the effective management of water (Kaize-Bosh et al., 1998). The RBWO aims to use informal institutions in the villages to improve water resources management by users. For this to be effective, grassroots water users must be aware of water allocation rules and regulations. Similarly, village leaders may be involved in the monitoring of water availability and quality through gauge reading and through developing and implementing by-laws for pollution prevention. There is hence a great potential for collaboration between institutions, yet this process needs great efforts in communication to involve stakeholders and an appropriate legal framework than can recognise and utilise the existing institutions. At the beginning of this study, the Rufiji Basin Water Office had little influence at the grassroots level over the use and

sharing of water resources. As a result of the RBWO's incapacity, and to develop synergies between formal and informal institutions, a new level of management was created: the sub-catchment Water Users' Association (Apex).

***Sub-catchment level: envisaged as the management level to articulate formal and informal management systems***

The Sub-catchment level was considered by RBWO as a potential way of assisting the RBWO in its role of allocating and controlling water uses in the basin as well as providing a framework where informal and formal arrangements could become complementary. The fact that the RBWO considers the Sub-Catchment level as an appropriate scale for managing water uses and water fees (using the APEX as an interface with water users) was of particular importance for the development of the DA. As chapters 6 and 7 will show, the managers from the RBWO will be the main end-users targeted by the DA developed in the present case study and it therefore attempts to provide information at the sub-catchment scale to provide end-users with some means of issuing water permits to APEXs, and more generally to enable them to reflect upon the impact of the decisions they take regarding planning activities at the sub-catchment level.

*Figure 11: Layout of WUAs (left) and of an AWUA (right) (Cour, 2006)*





Procedurally, emphasis is placed upon delegating responsibilities to stakeholders (through water users' entities) and to local government agencies (District Councils and River Basin Water Offices), in order to make the river basin or sub-catchment the planning unit. The novelty consists in the regrouping of the sub-catchment's various water users (irrigation committees, water users associations, and individual users) into an Apex.

Richard (2008) conducted a study in one of the sub-catchments of the UGRRC, the Kimani River Sub-Catchment (SC), to explore the institutional framework and the viability of WUAs in general and of the Apex Water Users' Associations in particular. This study showed that the "the number and diversity of the existing institutions in the Kimani SC present a problem with illustrating a single coherent picture of the responsibilities of resource management between them" (Richard, 2008:31). Table 7 shows that there are a high number of different structures involved in the management of water resources that operate at different scales and boundaries. The complexity of this institutional framework and the overlapping of responsibilities between various institutions and with the RBWO render difficult the effective management of water resources by the RBWO. As mentioned by CAWMA (2007), River Basin Authorities have basin wide mandate but are not endowed with the legal, political, or administrative power to achieve them. Their decisions are often "undermined by bureaucratic conflict because they infringe the competence of other government agencies and line ministries".

Table 7: Current institutional framework in the Kimani SC (Modified from Richard 2008, and authors' field work)

Institutions		Roles and Responsibilities
Local Government	<b>District Councils</b>	<ul style="list-style-type: none"> <li>• Empowered to make by-laws and approve the by-laws passed by the village government.</li> <li>• Awareness of water management issues and the requirements to form water user groups and associations.</li> <li>• Involved in the process of delivering water permits</li> </ul>
	<b>Village Governments</b>	<ul style="list-style-type: none"> <li>• The Village Assembly (VA) comprises all adults residing in the respective village and is the authority on policy-making in relation to the affairs of the village.</li> <li>• The VA elects 25 representatives who form the Village Government or Council (VC).</li> </ul>
	<b>Ward Authorities</b>	<ul style="list-style-type: none"> <li>• Collect revenue for the district council</li> <li>• Supervise the implementation of all planned activities at ward and village level</li> <li>• Coordinator between the council and villages, law-enforcer and security at ward level</li> </ul>
RBM Institutions	<b>Rufiji Basin Water Office</b>	<ul style="list-style-type: none"> <li>• Data collection, processing and analysis for water resource management, monitoring and assessment</li> <li>• Co-ordinate and approve SC water resource management planning and budgets</li> <li>• Approve, issue and revoke water use and discharge permits</li> <li>• Enforce water use permits and pollution control measures</li> <li>• Co-operate between sectors at the local level</li> <li>• Resolve conflicts and co-ordinate stakeholders</li> </ul>
Community Based Organisations in IWRM	<b>Water Users Associations (WUAs)</b>	<ul style="list-style-type: none"> <li>• Educate members on efficient water use.</li> <li>• Improve sources of income, through loans, searching for good markets for agricultural products of members, and through advertising the association inside and beyond the village.</li> <li>• Participatory planning of all activities regarding the control and use of water, building, managing and maintaining the scheme.</li> <li>• Apply for water rights.</li> <li>• Supervise, distribute and to conserve water within the WUA area.</li> <li>• Control water pollution</li> <li>• Bring legal proceedings against anyone who contravenes the rules and regulations of the association</li> <li>• Conflict resolution within and outside the area of the association</li> </ul>
	<b>Catchment Committees and Apex WUA</b>	<ul style="list-style-type: none"> <li>• Forum that brings together decisions makers from the districts in the catchment, the RBWO, sub-catchment Apex WUA and service providers.</li> <li>• Forum for water resources management and conflict resolution</li> </ul>
	<b>Service Providers</b>	<ul style="list-style-type: none"> <li>• WWF provides capacity building to the RBWO, districts and WUA in the form of financial and operational support and training.</li> <li>• Mbeya ZIO provides advice on irrigation and assistance with the building and maintenance of irrigation infrastructure. For example, the construction of the Uturo intake.</li> </ul>
	<b>Traditional Institutions</b>	<ul style="list-style-type: none"> <li>• Meeting of the elders, cultural groups, labour-based farming groups (<i>njaanwa</i>), local groupings for implementing water rotations (<i>kamati ya zamu</i>) and duty-based canal cleaning groups (<i>Maendeleo</i>) (Sokile and Van Koppen, 2003).</li> </ul>

### **3.6. Conclusions**

The main characteristics of the UGRRC as presented in this chapter can be summarised as follow:

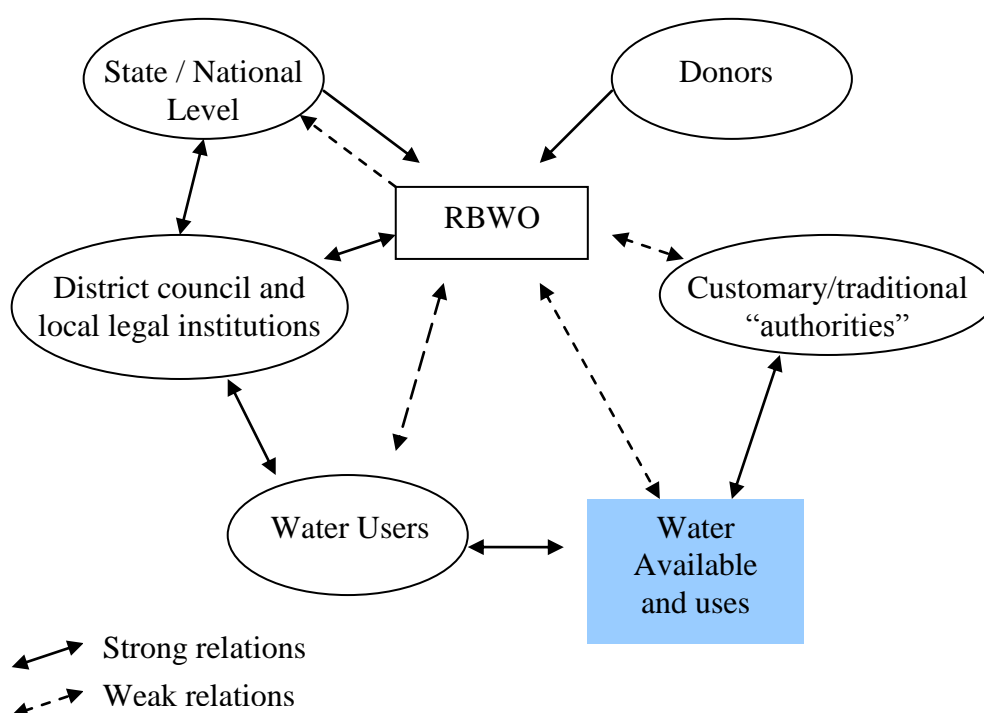
1. The existence of a plural legal system where the diverse customary systems are relied upon in getting access to and utilizing water resources
2. The RBWO empowered by the legal system to manage water resources but having a limited capacity to actually control water uses because of a legal system that does not consider the informal (customary) system sufficiently, and facing a significant lack of human, technical and financial means
3. A strong state and international injunction to implement reforms and perform informed management resources toward IWRM.
4. A strong social pressure to respond to the new demands, climate variability and other requests of water users or from politician having their own agendas
5. The existence of donor funded development projects proposing technical solutions in accordance with donors' agendas.

As it was noted earlier, for the majority of people in the Rufiji Basin, access to land and water for irrigation is regulated according to customary arrangements (informal), yet the government relies upon statutory (formal) arrangements for water management. Nevertheless, new approaches are being implemented or at least defined. For instance, the integrated approach (see section 3.3. ) that included the creation of river basin authorities (such as the Rufiji Basin Water Office) was a significant move made by the Tanzanian Government to solve the water crisis occurring in parts of Tanzania. But as very few human activities are regulated by statutory laws alone, neglecting customary laws may cause IWRM implementation to fail and have negative consequences for those individuals and groups who were better served by customary-based systems” (Maganga et al., 2002:6).

Some elements of answer to the challenges linked to the implementation of IWRM while at the same time taking account of customary arrangements were given by URT

(1995). This study recommended that the Rufiji Basin Water Office could focus on monitoring and allocation of water to identify basin-wide priorities and leave management functions at lower levels. The challenging roles endorsed by the Rufiji Basin Water Office when it was created, according to the URT (1995), required a comprehensive view of the basin's resources and uses. Because of the existing formal and informal frameworks, and because it is a rather new organisation (created in 1998), the RBWO stands in a situation where, in order to actually manage water resources, it has to strengthen its "relations" toward the national institutions as well as towards the local water users where local formal (Table 7) and informal institutions tend to prevail (see Figure 12).

*Figure 12: Relations between the RBWO and other "institutions" involved in the management of water resources in the UGRRC*



Motivated by these highly challenging tasks and by the political stakes involved in the upper part of the Great Ruaha Catchment (see section 3.5.1), the Rufiji Basin Water Officer requested to be provided with a tool that could provide a comprehensive view of the basin and the linkages between different water users. To answer that request the former technical co-operation project SMUWC (Sustainable Management of the

Usangu Wetland and its Catchment) initiated the development of the Usangu Basin Model. As a follow up to SMUWC, the RIPARWIN Project initiated the development of a decision aid (DA) through the intensive participation of stakeholders. This became the objective of the present PhD, i.e. to deliver a tool that could assist local institutions in fulfilling their task of implementing IWRM in the basin.

There are numerous factors that can reduce the chances of developing a DA that meets its purpose and that is actually used. As Malézieux (2001) states, one of them is the context within the DA is being used. This chapter has shown that the study area is a complex context. The UGRRC is a large catchment (54000 km<sup>2</sup>) comprising more than ten different main rivers which will pose scale problems when modelling the hydrology and will force modellers to divide the study area into smaller units. These units will have to match the hydrological and “management” units used by the potential users of the DA. The multiple water uses and furthermore their fast increase rate combined to the existence of informal norms guiding water uses is as well another challenge. Formal water permits cannot be used to estimate and to control water uses in the DA.

The lack of technical, human and financial means combined to the formal/informal dimensions of water management in a changing environment where strategic water uses (agriculture/hydropower/environment) represents another challenge for the modellers. The end-users, such as water managers from the RBWO, will have very high expectations concerning what the DA must achieve which may render difficult the identification of their needs. For these reasons, developing a DA for such users in a study area as complex as the UGRRC appears already very challenging.

## **Chapter 4 - Design of RUBDA v1: Analysing the participation process in designing a research Decision Aid for IWRM**

Chapter 4 is the first of three chapters that reflect on the development of the DA built to assist water management in the Ruaha River basin. This chapter examines the design of the first version of the Ruaha Basin Decision Aid (RUBDA v1) by focusing on the participation of end-users. The next chapter (5) explores the development of RUBDA v1 leading to the second version; RUBDA v2, while Chapter 6 explores the performance of RUBDA v2. In this chapter are analysed the means used to get the end-users to participate, the outputs of the participation process and the way developers and project partners interpreted the end-users requests. By doing so, it also contributes to answering the first research question by examining the requirements for designing a DA for IWRM. The results presented in Chapter 6 also contribute to answering the second research question by examining the interactions between the project partners and users (and their influence) through an early and effective participation of end-users during the development of a DA for WRM (as urged for in the literature, see Chapter 2) can solve the flaws inherent to DAs that contribute to their non use. The chapter shows that the involvement of end-users in the design of RUBDA and the way their inputs were translated by the developers and project partners into specifications for the DA strongly shaped the final design of the DA. This participatory process helped to understand users' needs and design the DA accordingly.

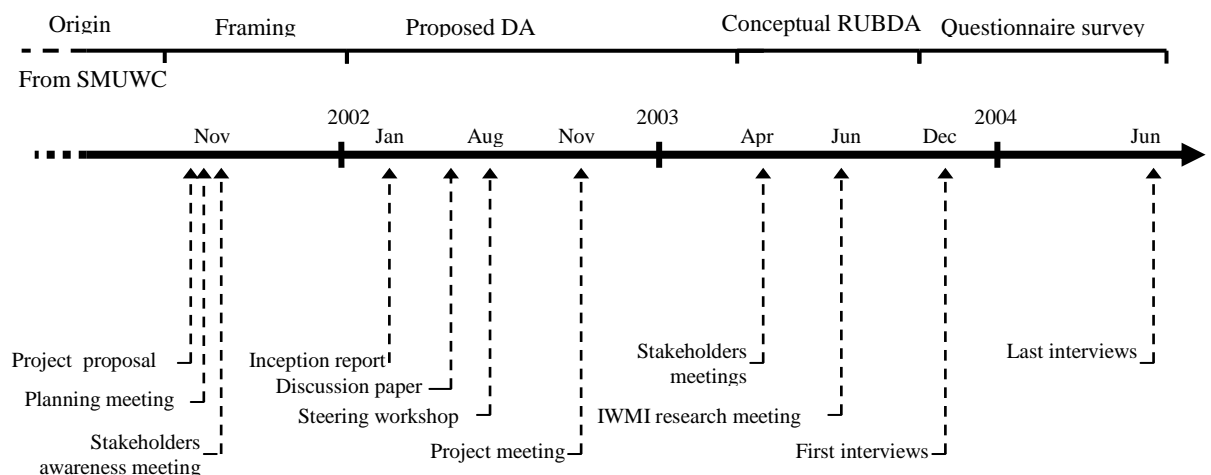
### **4.1. Introduction**

The purpose of this chapter is to describe the first step of the development of the Ruaha Basin Decision Aid version one (RUBDA v1) from its origins to the end of its design. The chapter reviews the various phases of the design of RUBDA v1 and pays special attention to way the participation process was conducted. Effective participation of users should allow a better understanding of their requirements and expectations (Welp, 2001; Mysiak et al., 2005). In the literature, there is unanimous agreement that user involvement is a prerequisite to the successful adoption and use of DAs (Mysiak et al., 2005; De kok, 2003). The participation of DA users in the development of RUBDA

forms an important component of this chapter and of the thesis. A review of the participation process, especially the extent to which users and project partners contributed to the design of RUBDA, aims to provide better understanding of the characteristics of RUBDA as developed following a design phase.

The chapter reflects on work undertaken by actors involved in the RIPARWIN project (that started in 2001) and especially on the development of a DA for the management of water resources in the UGRRC in Tanzania. The author was involved in the delivery of the outputs produced by RIPARWIN from November 2001 onward. Figure 13 shows the time line and main events in the design of RUBDAv1 between November 2002 and June 2004.

*Figure 13 : Chronological diagram presenting the main events of the design of RUBDA v1 (2001 to 2004)*



The RIPARWIN project outputs are described and analysed in their chronological order to allow a better understanding of the evolution of the different concepts linked to the development of the DA. The next section describes the origins of the DA development initiative. Sections two to four present the framing of the DA initiative by the project partners, the DA that was proposed, and the design of the conceptual RUBDA, respectively. Throughout these phases, the participation of users was enabled through workshops and meetings with a large variety and number of stakeholders. The fifth section presents the last phase of the design of RUBDA, during which a questionnaire survey was conducted with the main users targeted by RUBDA. The sixth section

summarises and assesses the participation process and its outputs during the different phases and their impact on the design of RUBDA.

#### **4.2. Understanding the origin of the Decision Aid**

RIPARWIN was both a new project with its own objectives and a follow up to the former technical co-operation project Sustainable Management of the Usangu Wetland and its Catchment (SMUWC). Many recommendations proposed by the SMUWC were taken on board by RIPARWIN, including the suggested development of a DA. At the same time, the Rufiji Basin Water Office (RBWO) stated its need for a water resources management tool for one of the Rufiji sub-catchments: the UGRRC. With this demand from the RBWO in mind, and given the fact that it is agreed among researchers that models in general and DAs in particular are still demanded by donors (e.g. DFID, 2008) in development projects in the field of water management, it was logical that the development of a DA would become part of RIPARWIN's activities.

The decision to include the development of a DA for the management of water resources in the UGRRC was taken by the project leader in 2001. This decision had two origins as described above, yet the belief that a DA was the appropriate means to assist the management of water resources, shared by the three research partners involved in RIPARWIN, had deeper origins.

These origins relate to the wider context of water management in the UGRRC. Such management was the result of a long sequence of development interventions and initiatives that have, one after another, attempted to rationalize the management of water resources. A "command and control" approach was adopted as the proper way of managing water abstractions. In this context, having good knowledge of the available water and its uses is critical for making decisions regarding the allocation of water. Decisions, after all, must be based on sound information if they are to be rational and realistic.

A "rationalisation" process in the study area started in the late 1980s when a series of projects attempted to improve the productivity of agriculture and water efficiency. The



given rationale was that the productivity of water of indigenous smallholder systems was low and that irrigation intakes had to be transformed from traditional to modern practices in order to allow better control of water uses and resources (Lankford, 2004).

**Box 4: Four irrigation improvement projects (Lankford 2004)**

“These indigenous systems have been the focus of several irrigation improvement programmes and become termed by many as “improved” irrigation systems. There have been four key improvement projects:

(1) The Usangu Village Irrigation Project 1985–96 (UVIP, 1993). This was funded by the FAO and aimed to upgrade six indigenous furrows. Work was completed in three of these systems.

(2) The Kapunga Rice Project, 1988–92. This project had three components: the building of a parastatal farm, the building of a smallholder irrigation scheme and improving the existing smallholder irrigation systems abstracting from four intakes on the Chimala River.

(3) The Kimani Irrigation Project (KIP), 1991–94. This project, funded by the Canadian International Development Agency (CIDA), planned to upgrade 4300 ha of irrigated agriculture in the Kimani Sub-Catchment, of which only 500 ha was completed.

(4) Smallholder Irrigation Improvement Component (SIIC), 1997–2001. This programme was part of the World Bank-funded River Basin Management and Smallholder Irrigation Improvement Programme (RBMSIIP). Under this programme two indigenous furrows were upgraded.

All of these programmes had two combined aims: to improve agricultural productivity (by increasing yields and expanding the irrigated area) and, within the indigenous smallholder systems, to increase the efficiency of water use. The project documents imply that indigenous systems are unproductive (with average yields of 2.5 t/ha of paddy) “ Lankford (2004)

The projects achieved a number of tasks (see Box 4) such as modernising intakes, upgrading traditional furrows and building new modern irrigation systems. But according to Lankford (2004), the targeted objectives were not achieved: Yields were not increased and efficiency was not improved. Instead, these projects disrupted the flow to the Great Ruaha River and to other downstream users. The failure of these projects stems from their “ill conceived judgement that the indigenous systems were less efficient than the ‘modern improved system’, without analyzing the implications of the improvements” (Lankford, 2004).

The impacts of these projects, which promoted a more “controlled” management of water resources in the area, were not positive regarding the low dry season flows in the Great Ruaha River (Lankford, 2004).

At the end of the 1990s, the rivers were still drying up during the dry season and the demand for water kept rising because of an ever-increasing population in the area. The RBWO requested help to manage the upstream part of the basin, i.e. the UGRRC, because rising water scarcity had created high competition between water uses. In response, the SMUWC project was commissioned. It was asked to develop a hydrological model for the area called the Usangu Basin Model (UBM). When the SMUWC project ended in 2000, it left behind a considerable amount of work but still more questions than answers. The hydrological model that was built by SMUWC was not a success because it was not user-friendly, was incomplete, and remained unused. The need to have a tool to assist the basin office in managing water resources was increasingly present in the managers’ minds. Although the command and control approach adopted during the 1990s had not generated significant improvements, changing strategy was not perceived to be an option. A lot of the traditional intakes had been transformed into concrete modern intakes and the use of water was by this time subject to regulations and water permits. Controlling the use of water was perceived by the Ministry of Agriculture and the Ministry of Water and Livestock to be the only way to reduce the over-use of water in the upstream part of the UGRRC.

When RIPARWIN was launched, the concept of IWRM had already been largely accepted as the proper way of managing water resources. Managing water resources is a complex task, even more so when it has to be done in an integrated manner. To

overcome this complexity, one of the fashionable solutions proposed by scientists and donors (UNPD 2006, DFID 2008, ADB, 1999) is to provide water managers and other stakeholders with various technical tools that aim to support the management of water resources. DAs are part of the tools seen to be appropriate. Thus, tools in general, including DAs were, and are still included in development projects. Once incorporated into RIPARWIN's objectives, the concept of the DA evolved according to the discussions, reviews and meetings held during the project's initiation phase. The next section presents the evolution of descriptions of the DA from project documents to provide insights into the main influences.

#### **4.3. Framing of the DA initiative: Development of a simple management tool?**

This section reports on analysis to assess the way the DA was perceived by the different actors involved in the project and to observe the way in which the DA was referred to and described. The aim is to show how the DA's design was influenced and for what purpose it was developed. Analysis of the project documents is presented in chronological order. From the project proposal to the first project paper which presents the conceptual DA, including the literature review, the most notable phenomenon is that the project was responding to the managers' demand for a simple management tool by proposing a research DA. The DA was designed as a research tool to explore management scenarios and to provide a better understanding of the basin characteristics, and built according to the IWRM principles adopted by the international researchers involved in the project.

The four main project documents produced during the first year of the project and analysed in this section are:

1. The project proposal (RIPARWIN, 2001a)
2. The proceedings of the planning meetings (RIPARWIN, 2001b)
3. The proceedings of the stakeholder awareness meeting (RIPARWIN, 2001c)
4. The produced inception report (RIPARWIN, 2002)

The project documents analysed were produced for internal use and were neither disseminated nor published but can be found on the RIPARWIN Final Technical Report CD. At the outset of RIPARWIN a planning week occurred during which several meetings were conducted to familiarize the project team with the key issues facing the research programme, generate a broad-scale research plan and identify preliminary plans for research topics. The first meetings were conducted between research partners but the planning week also included a stakeholder awareness meeting to introduce RIPARWIN to Tanzanian stakeholders and to get their feedback in order to improve RIPARWIN's objectives and scope.

The first document, RIPARWIN's proposal (RIPARWIN, 2001a), describes the objectives and log frame of the project as they were accepted by DFID<sup>4</sup>. The project log frame was then discussed in a series of meetings with both project partners, namely international and Tanzanian researchers, and local partners such as district council officers, members of the ministries of agriculture and water, or staff of the RBWO.

The second and third documents present the discussions held during the inception phase meetings between the project partners (RIPARWIN, 2001b) and with the local stakeholders (RIPARWIN, 2001c). The last document, the inception report (RIPARWIN, 2002), presents the revised log frame and objectives of the project according to the discussions held during the inception phase. The analysis of these documents aims to show how the DA was imagined when RIPARWIN was initiated, how the project partners and the stakeholders perceived it, and what impacts the consultations held during the inception phase had on the way the DA was then defined in the inception report.

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<sup>4</sup> The Department for International Development, or DFID, is a UK government agency

### **4.3.1. RIPARWIN project proposal**

RIPARWIN was an action research project and the project partners were three research institutes<sup>5</sup>. Most of the field work and data analysis were conducted by Tanzanian PhD students supervised by researchers from the three research partners. The overall aim of the project was to research irrigation and river basin management. By conducting this research work the project intended to “assist basin stakeholders by providing analysis, tools, and strategy and policy advice, mainly in Tanzania, but also to a wider audience” (RIPARWIN, 2001:12).

As stated, the research work intended to generate knowledge and tools (within which the DA is included) that would assist basin stakeholders. The types of analysis, tools and advice produced by the project, however, were of different nature. They could have been the result of research conducted by researchers on topics of interest for them as individuals or as institution/donor representatives. If this were the case, the benefits generated by the research for the basin stakeholders could be considered a side effect of the project. There is a lot of literature available on the relations between donors’ objectives and projects’ objectives<sup>6</sup>, however what is of interest here is the context within which the DA initiative was framed. Was the DA planned as a research tool to be used by researchers and benefiting basin stakeholders, or was the DA (as its name implies) a tool designed for and with the basin stakeholders that will use it to take decisions? If the latter were the case, then the project would need to answer basin stakeholders’ requests and to define its research objectives accordingly. For RIPARWIN, research was the main objective of the project, but it was also trying to answer the demands of basin stakeholders such as those raised by the RBWO or the Ministry of Agriculture. This “in-between” position was both the will of the project leader and one of the conditions imposed by the main funder of the project, DFID. The

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<sup>5</sup> The University of East Anglia through its Overseas Development Group based in the UK, the International Water Management Institute office in South Africa and the Sokoine University of Agriculture through its Soil and Water Management Research Group in Tanzania.

<sup>6</sup> There are debates about Aid policy and the fact that development projects are bound to follow the agendas of donors instead of following the requests made by the governments and actors of the country targeted.

DA initiative fell within the same position: it was a tool for researchers, but had also to answer stakeholders' needs.

In the project proposal produced in November 2001 (RIPARWIN, 2001a), the log frame includes the following objective:

*“Enhanced understanding by water professionals of river basin characteristics, climatic & allocation means, risks and typologies within semi-arid climates through production of a river basin management decision-aid”. (RIPARWIN, 2001a:5)*

Thus, the stated aim of the DA was to target “water professionals” and to enhance their understanding of various issues linked to the management of water resources. Because of the broad meaning of most of the words and concepts used in the quotation, its deconstruction might not reflect the authors' ideas. The term “water professionals”, if referred to the definition of professional as ‘an individual that engages in a pursuit or an activity’, means that anyone whose profession is linked to the water ‘sector’ would benefit from the development and use of the DA. It encompasses, for example, water managers from the government, researchers, as well as users themselves. The DA is therefore targeting a very broad range of users. Yet, there is no mention of whether these water professionals will directly benefit from it as users, or indirectly if it is used by the researchers. There are three issues that the DA must tackle to locate the basin within the wider framework of river basin management: An exhaustive description of the basin (basin characteristics), the management of water resources per se (climatic and allocation means, risks), and the classification of river basins within semi-arid climates. At this stage, the description of the DA was kept very broad.

#### **4.3.2. First DA Planning meeting**

The planning meeting was held between fourteen researchers from the three project partners, namely ODG, SWMRG and IWMI. It was the first project meeting organised under RIPARWIN. During this meeting, six research topics were identified (RIPARWIN, 2001b). Each research topic was attached to an individual RIPARWIN research associate. One of the research topics was defined as “Decision-aid, risk,

WEAP<sup>7</sup> and hydrological model”. The title of the research topic refers to a water allocation model, the WEAP model, being tested and promoted by IWMI. “Hydrological model” is also mentioned, and though it certainly refers to the hydrological model called Usangu Basin Model developed by SMUWC, this is not stated. A review of the meeting proceedings (RIPARWIN, 2001b) reveals more about the state of mind or interests of the project partners than about a proper project programme. The discussion did concern the project log frame *per se* but not the topics and research orientations that the research associates could explore. Nevertheless, it provides some indication about the influences that may have affected the design of the DA. The fact that the WEAP model is mentioned and even included in the title of the research topic is an indication of IWMI researchers’ influence. The WEAP model is a licence free software developed by the Stockholm Environmental Institute (SEI) and the University of Boston. WEAP was adopted by IWMI following some lobbying activities by SEI that led to its implementation by IWMI in several locations across the world (it was tested or applied in more than 20 countries<sup>8</sup>). The opportunity for IWMI to have WEAP model used, and the improvements achieved on WEAP following its first application, were sufficient reasons to get the WEAP model proposed as an appropriate one for RIPARWIN purposes. However, IWMI’s proposal of the WEAP model did not reveal an attempt by the organisation to sell one of its products. The software is free and its use was legitimated by the fairly good results obtained during its first implementations (Levite et al. 2002, Arranz 2007).

Under the research topic “Decision-aid, risk, WEAP, hydrological model” some research questions were identified by the project partners:

What are the water needs of sectors?

What are the jobs and livelihoods within sectors?

What are the likely future demands, options and scenarios?

What are the risks associated with options/impacts?

What are dynamics of hydrology (Including groundwater)?

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<sup>7</sup> Water Evaluation and Planning Tool is a water allocation model (<http://www.weap21.org/>)

<sup>8</sup> <http://www.weap21.org/>

Research questions 1, 4 and 5 were direct uptakes of the desire to include the description of the basin characteristics and risk analysis mentioned in the log frame, whereas research questions 2 and 3 were significant inputs to the DA's terms of reference. Research question 2 actually introduced a new dimension in the research topic linked to the development of a DA: Economic analysis. It implied that the DA had to provide information about the value of water in terms of jobs and incomes linked to each water sector. Research question 3 involved conducting prospective analyses of the basin. Research questions 2 and 3 were new inputs that would significantly shape the design of the DA. In summary, the DA had to describe the status of the basin in terms of hydrology, risks and water demands, as well as to deal with economics and to explore prospective planning.

#### **4.3.3. Stakeholder awareness meeting**

Following the first meetings held between research partners, a meeting was held in November 2001 with Tanzanian stakeholders. About forty participants from outside the project attended the workshop (RIPARWIN, 2001c). Most of the participants belonged to national organisations such as the Vice President's Office, the Ministry of Water and Livestock, the Ministry of Agriculture, the Ministry of Natural Resources and Tourism, National Environmental Management Council, the Mbarali and Iringa Districts Councils, the Ministry of Environment, the Ruaha National Park, the Tanzania Electric Supply Company Limited, the Tanzania Meteorological Agency, the Zonal Irrigation Office, the Mbeya Zonal Irrigation Unit, the Kilimanjaro Agricultural Training Centre, the Rufiji Basin Water Office, and the Rufiji Basin Development Authority. Some participants were researchers from other research organisations such as the Sokoine University of Agriculture, the Southern Highlands Agricultural Research Institute, the Tea Research Institute of Tanzania and the University of Dar es Salaam. There were also participants from other projects, namely SMUWC and MAFS/ASPS –DANIDA and the HIMA Iringa Project. Representatives of some of the largest private water users located in the UGRRC also attended. These participants represented the Kapunga Rice Project, the Mtibwa Sugar Estates Limited, the Madibira Smallholder Agriculture Development Project, and the Mbarali Rice Farms Limited.



The meeting was an opportunity to present RIPARWIN to Tanzanian stakeholders and to get their feedback on the project objectives and proposed outputs. The workshop also provided an opportunity for the project to gain a high profile within Tanzania (RIPARWIN, 2001c). During the meeting, the rationale, objectives and outputs of the project were presented. The participants were asked to react to the presentations. The meeting proceedings (RIPARWIN, 2001c) provide details of some of the issues raised by the participants. The issues concerning the DA and the responses given by RIPARWIN researchers are given below:

1. Dynamic nature of irrigation, for instance farmers are unsure of the start and end of the season. Presently they use river levels; they need better advice.  
⇒ This could be part of the DA, and it will be an important part of RIPARWIN
2. Analysis of water rights and abstraction rates, and fees.  
⇒ This is already an important part of RIPARWIN
- 3. Development of a simple water resources management tool**  
⇒ RIPARWIN agrees to examine and address this issue
4. Assess the present mechanisms of water allocation, the need for proportional allocation during shortages and co-ordinated water use planning
5. The fragmentation of past projects has led to inaccessibility of information/data, RIPARWIN must act differently.  
⇒ RIPARWIN agrees to examine and address this.

Source: modified from RIPARWIN (2001c:11)

Apart from the last comment, made by unknown participants, all the comments listed above were made by officials from the Ministry of Water and Livestock Development. These issues provide some information about the participants' concerns and needs. Firstly, this is the first project document which records the Ministry of Water and Livestock (through the Rufiji Basin Water Office) requesting a simple management tool. Secondly, it shows that there is a demand for a DA (see issue 1) built for farmers, that would assist their decisions concerning plantation dates. Other important issues that can be related to the DA, concern water rights, water allocation mechanisms especially during water shortages, and the need for better accessibility of information and data.

At the end of the inception meeting it was decided that RIPARWIN (as part of its capacity building strategy) would aim to:

*“build a RBM decision-aid that suits stakeholders and is owned by them, and assist the ministry of MOWL [Ministry Of Water and Livestock], the RBMSIIP and the RBWO to manage water resources at the sub-catchment level.”*  
(RIPARWIN, 2001c:18)

At this point the discussions about what kind of DA had to be developed were limited to those that occurred during the planning meetings between researchers and during the stakeholder awareness meeting. Towards the end of the inception phase, the DA had been described in many different ways.

The DA must be a simple tool that must target water professionals in general, but more specifically those of the MOWL, the RBMSIIP and the RBWO but must also answer needs of farmers. The DA must enhance the understanding and provide decision support to the targeted users by providing information concerning the river basin characteristics, the climatic and allocation means, the hydrology, the risks and typologies, the water demand, the economics of water uses, the plantation dates as well as explore planning options. Furthermore, the DA must provide information for the whole of the UGRRC as well as assist the management of water resources at the sub-catchment level. In short, the DA had the challenging objective of incorporating many ambitious aims and potential users.

#### **4.3.4. The inception report**

In January 2002, an inception report was produced (RIPARWIN, 2002). The report aimed to clarify the project objectives and activities as a follow up to the project proposal and to take on board the comments collected during the inception phase and make necessary modifications. Some significant inputs were made during the planning workshop and the stakeholder awareness meeting held in November 2001. The inception report shows how these inputs shaped the DA. It first says that the collaboration with IWMI was much greater than first foreseen, to the extent that the Ruaha River Basin will be treated as if it were a benchmark basin for long term research into river basin management and in the future may be designated as such. IWMI

involvement increased due to greater co-funding which led to an expansion of the research.

The inception report also stated that RIPARWIN fulfils an important need of the RBWO: The development of a DA for the management of water resources. It also said that, following the discussions held during the planning meeting, WEAP was being considered as a platform for the DA and that some of the RIPARWIN members had completed WEAP training in South Africa (January 2002). However, there is also mention that wide consultation within Tanzania was needed, particularly with the RBWO, to determine the scope and content of the DA.

The inception report reveals that apart from increasing its involvement in the project, IWMI strengthened its relations with Sokoine University of Agriculture and its research centre (the Soil and Water Management Research Group, SWMRG) by signing a Memorandum of Understanding for mutual long-term co-operation. The inception report shows that IWMI's influence in the project increased. For instance it is proposed that the literature review of the project concerning WRM would be achieved by IWMI. Since IWMI supported the implementation of IWRM, its greater involvement in the project also implied a greater influence of the concepts put forward by IWMI. There was also a proposition by IWMI that the UGRRC could become a benchmark basin. It was even added as a new project output in the log frame. The project had to register the studied basin with the UNESCO HELP programme. The HELP programme aimed at <sup>9</sup>:

*“creating a new approach to integrated water resources management through active involvement of both policy and facilitating (water and land resource managers) groups to set the policy agenda and ensure that scientific results will benefit society's needs through a re-look at policy and management practices.”*

It also said that through SUA and SWMRG, the project had been linked to the Soil and Water Management Research Network for East and Central Africa.

The combined influence of IWMI and the willingness of the project to adopt the concerns of the international community also impacted upon the design of the DA. For

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<sup>9</sup> Source : <http://www.wrc.org.za/downloads/events/FW%20HELPSS07%20-%20Announcement.htm>

instance, the research topic linked to the development of the DA became “Modelling, cost-benefit analysis, decision-aid for planning; WEAP modelling; Usangu model improvement”, in order to answer to the request made by IWMI to include economic analysis and have the WEAP model applied in the study area. Apart from the WEAP model added by IWMI and the Usangu Basin Model improvement derived from the SMUWC project, the new important component added to the DA was cost-benefit analysis. Linking water management and allocation to the monetary productivity of water was one of the core IWRM concepts.

The main contributions of the inception phase to the way the DA was perceived was the idea that the DA would be a planning tool mainly targeting the Ministry Of Water and Livestock and the RBWO. The DA would entail a hydrological model and the WEAP model, and would include cost-benefit analysis. But the overall objective of the DA remained the same: the DA had to be a research tool to enhance the understanding by water professionals of river basin characteristics, allocation means, risks and typologies within semi-arid climates. The request made by the RBWO to get a simple management tool was taken on board but not as a constraint or requirement that would guide the design of the DA rather as a justification for the RIPARWIN project and its outputs: A key partner organisation was in need of a DA and RIPARWIN would fulfil that need.

After the inception phase, a discussion paper on the DA was produced (Rajabu, 2002). On the basis of the literature review conducted about Decision Support Systems (DSS) and DA, a conceptual DA was proposed. The next section shows how the DA became a research tool for the implementation of IWRM.

#### **4.4. The proposed Decision Aid: a research tool for IWRM**

The discussion paper titled “Development of a decision support system (DSS) for the great Ruaha Basin in Tanzania” (Rajabu, 2002) was written in July 2002 by the research associate in charge of the development of the DA prior to my arrival on RIPARWIN. The paper presented a review of literature concerning hydrological modelling and

models, river basin modelling and DSS. It described the proposed DSS<sup>10</sup> (DA), the expected outputs as well as the decisions to be supported. The term Decision Aid had been used in all the project documents up until this discussion paper. The proposed DA (or DSS as mentioned in the paper), was then presented to the stakeholders during the first steering workshop in August 2002. The discussion paper and the presentation made during the steering workshop were critical because they presented the first fairly precise plan of what the DA would be. The workshop was in fact the first step of user participation in the development of the DA, and furthermore the first validation by the stakeholders of the proposed DA. A project meeting held in Tanzania in November 2002 between the project research partners was also described in this section. During this meeting, key decisions were taken about the development of the DA, such as its final name (RUBDA) and the need to recruit another research associate to implement the development of the DA. Following this meeting, the decision to hire me in RIPARWIN was taken.

#### **4.4.1. The discussion paper**

As the discussion paper (Rajabu, 2002) was produced at an early stage of the project, and considering the level of detail given, it can be considered as the first draft of the DA components and of the development methodology. It is a representative output of the inception phase because it includes most of the evolution and contributions described in the previous sections of this chapter. The contributions made by the IWMI researchers were all taken on board and significantly influenced the proposed DA. As requested by IWMI, the use of WEAP and the estimation of cost-benefit analysis of water uses were part of the proposed DA. However, the request made by the RBWO to get a simple management tool was already being challenged by the complexity of the DA being proposed. Furthermore, a clear shift had been made: The tool was then expected to perform an integrated analysis in order to allow the implementation of IWRM, as the literature review shows.

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<sup>10</sup> The RIPARWIN project did not distinguish Decision Support Systems from Decision Aid. In the literature there isn't any real difference between DSS and DA

## The Proposed DA

The literature reviewed in the discussion paper was clearly oriented towards the technical aspects of modelling. It described the different types of models, technologies and validation methods available but did not linger on the involvement of users. Based on this literature review a DSS was proposed, defined as follows:

*“Integrated water resources planning and management requires that a large amount of information is gathered and brought together in a framework capable of undertaking an integrated analysis. A river basin management DSS should focus on a basin-wide representation of the water availability, water allocation and water uses and must also be user friendly and more applicable for non-specialists. Therefore, the DSS to be developed will operate on the GIS -ARC View environment in order to make the work/results more transparent to stakeholders...” (Rajabu, 2002:6)*

This definition reflects the following key points::

- Water must be managed in an integrated manner
- Complexity is key for integrated analysis
- User friendliness is critical for user uptake of the tool
- GIS technology is a means to reach the targeted user friendliness
- There is no mention of the decisions that need to be supported or aided
- The end-users’ involvement is not mentioned.

To be in line with the above-stated choices, the planned DSS was composed of a rainfall-runoff model, a channel routing model, a reservoir operation simulation model, routines to model agricultural, industrial, domestic and environmental water demands, and a linkage to an economic analysis model that translates the outcomes from the water resources simulation model into financial values. It was proposed that the Usangu Basin Model (UBM) would be used for rainfall-runoff and channel routing modelling,

whereas reservoir operation, agricultural, industrial, domestic and environmental water demands would be modelled using WEAP<sup>11</sup>.

Another important aim of the DA was to collate data concerning the UGRRC, and to provide it to the users. This would have been done by including two databases in the DA (Rajabu, 2002). These two databases were called DSS Database Management Systems. The first system was a relational database which would have related information in a tabular way. The second was a Geographic database (or Geographic Information System), which would have related information pertaining to fundamental map features.

The DA proposed in the discussion paper (Rajabu, 2002) was an instrument designed to perform integrated management of water resources by defining and evaluating alternative water management allocation plans. It used knowledge about the nature of the physical processes operating in the system (the UGRRC) to make prospective scenarios concerning the future behaviour of that system. The hydrological model was used to extrapolate hydrological data series and to make decisions in relation to planning, design, operation and management of water related issues. These decisions were rational and needed to be informed by the available resources, the environmental impacts and the social and economic impacts. To go beyond hydrological modelling, the DA would include an economic analysis model to generate the environmental, social and economic impacts of the scenarios' run. The outcome model would need to transform the daily river flow results into average annual or monthly water balances before using them to assess the social, environmental and economic indicators (Rajabu, 2002).

The hydrological model was a mathematical model that can be described as a hybrid, because it was composed of different types of sub-models. The sub-models were deterministic hydrological models that represented physical processes by sets of equations. They can be classified as lumped, because they averaged spatial variations of the hydrological variables and parameters. However, the sub-model for rainfall runoff

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<sup>11</sup> WEAP was not the software chosen to be included in RUBDA but at this point of the project development it was the first option.

processes in the high catchments was considered to be a semi-distributed (as opposed to lumped) model: It divided the high catchments into 13 sub-catchments to consider the spatial variation in rainfall (SMUWC, 2001). The sub-models also differed because some of them were developed as conceptual<sup>12</sup> models, such as the Rainfall Runoff Model or the Western Floodplain Model, whereas others such as the Eastern Wetland Model or the Routing Model were developed as empirical<sup>13</sup> models.

### **Proposed methodology**

A DSS development methodology, composed of eight phases, was also proposed in the discussion paper. The proposed methodology is given bellow (paraphrased from Rajabu, 2002):

1. Selection of appropriate model/models: The Usangu Basin Model and Water Evaluation and Planning Tool (WEAP) were proposed.
2. Schematisation (network representation) of the Great Ruaha Basin to be used for WEAP. Study of the boundaries of the area and of the river network. Homogeneous demands and resources for which further differentiation is not required would be lumped together to simplify the schematic.
3. Set out supply priorities, demand preferences and allocation order. A structured questionnaire, administered by the researcher, would be used to collect the data.
4. Establishing the baseline scenario (current operation of the system). This would be done by examining and analysing collected and measured hydrological data, climatic data, irrigation water use and abstractions, reservoir and hydropower generation and water use data, rural and urban domestic water supply data, fisheries, wildlife and livestock water use data.
5. Calibration and validation/verification of the model using collected data.
6. Development of scenarios. Probable water use scenarios for modelling would be identified and developed through a process of unstructured discussions

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<sup>12</sup> Outputs are produced using the knowledge of the relevant physical, chemical, and biological processes that act on the input.

<sup>13</sup> The outputs are inferred from statistical relationships derived between the outputs and selected inputs.



with managers, water users, policy makers and others. Each interviewee would be asked to identify five future use scenarios perceived as significant.

7. Evaluation of the impact of different water demand and climatic scenarios on the water resources system. This would be done by simulation of different scenarios of stream flow and water withdrawal) levels using the developed model and examining demand and supply resources results.
8. Estimation of the cost and benefits of delivering water from supply sources to different demand sites.

The proposed methodology highlights the importance given to the modelling as compared to the very limited weight given to the involvement of users. Users were only to be involved to define the scenarios that will be run by the DA. Furthermore, the choices concerning which models were to be used, which decisions had to be supported, or the type of results produced did not require users' involvement. This implies that these choices were to be made by the DSS developers: Project hydrologists and water experts. This appears surprising, especially when considering that the DSS needed to be user oriented. But it has to be linked to the belief that IWRM was perceived as the only solution for good management of water resources, and that assisting water managers' in their application of IWRM would necessarily fulfil their needs. In the paper, some of the users of the DA were described as "non-specialist", reinforcing the underlying assumption that the knowledge of what must be a DA belonged to the developers. Another very strong assumption underlying the whole discussion paper was that all actors involved in water management, including decision makers, were willing to implement IWRM.

#### **4.4.2. The steering workshop**

The steering workshop was organised in August 2002 (RIPARWIN, 2002b) to present the progress made by RIPARWIN to Tanzanian stakeholders. There were approximately 30 participants from the various ministries, government institutions and NGOs. The first draft DA that was presented was based on the discussion paper. The draft DA was named the River Basin Management Decision Aid (RBMDA).

The rationale of the RBMDA as given in the presentation was that it would allow:

- A move beyond hydrological modelling
- The incorporation of scenarios (“what if?” questions)
- Users and researchers to be reminded of the complexity of river basin management.

The RBMDA was defined as a management tool that would assist users by defining problems, generating alternative solutions, evaluating alternatives, and indicating the best alternative for implementation. To achieve these objectives, the proposed RBMDA would entail a database management system and the Ruaha Basin Hydrological Model (based on the UBM), a graphics / schematisation model (WEAP), and River Basin Management Modules (RBMM) to describe river basin management issues. The River Basin Management Modules were a new component of the DA that was not described in the discussion paper. It was divided into eight different themes about critical issues that managers need to be aware of: Economics and livelihoods, institutions, policy and legislation, inter-sectoral allocation, irrigation in river basins, other water needs, process management, supply management and other alternatives, and risk analysis. The River Basin Management Modules also included a component which generates a “report” (word document) summarising major issues (data, scenarios, outputs analysis).

During the steering workshop the RBMDA was presented by the research associate in charge of the hydrological analysis and the development of the DA. The rationale, aims, and components were presented and validated by the participants. Apart from stating that a DA for the management of water resources was needed, there were very few comments made by the participants during the workshop. Nevertheless, this workshop was critical because it was the first validation of the proposed DA. From this presentation until the end of the project the core facets of the DA (hydrological modelling, GIS, scenario creation and integrated analysis) were adopted. The steering workshop was the first step of DA users’ participation in the development process. During the workshop some participants validated the idea of developing a DA for the implementation of IWRM (RIPARWIN, 2002b).

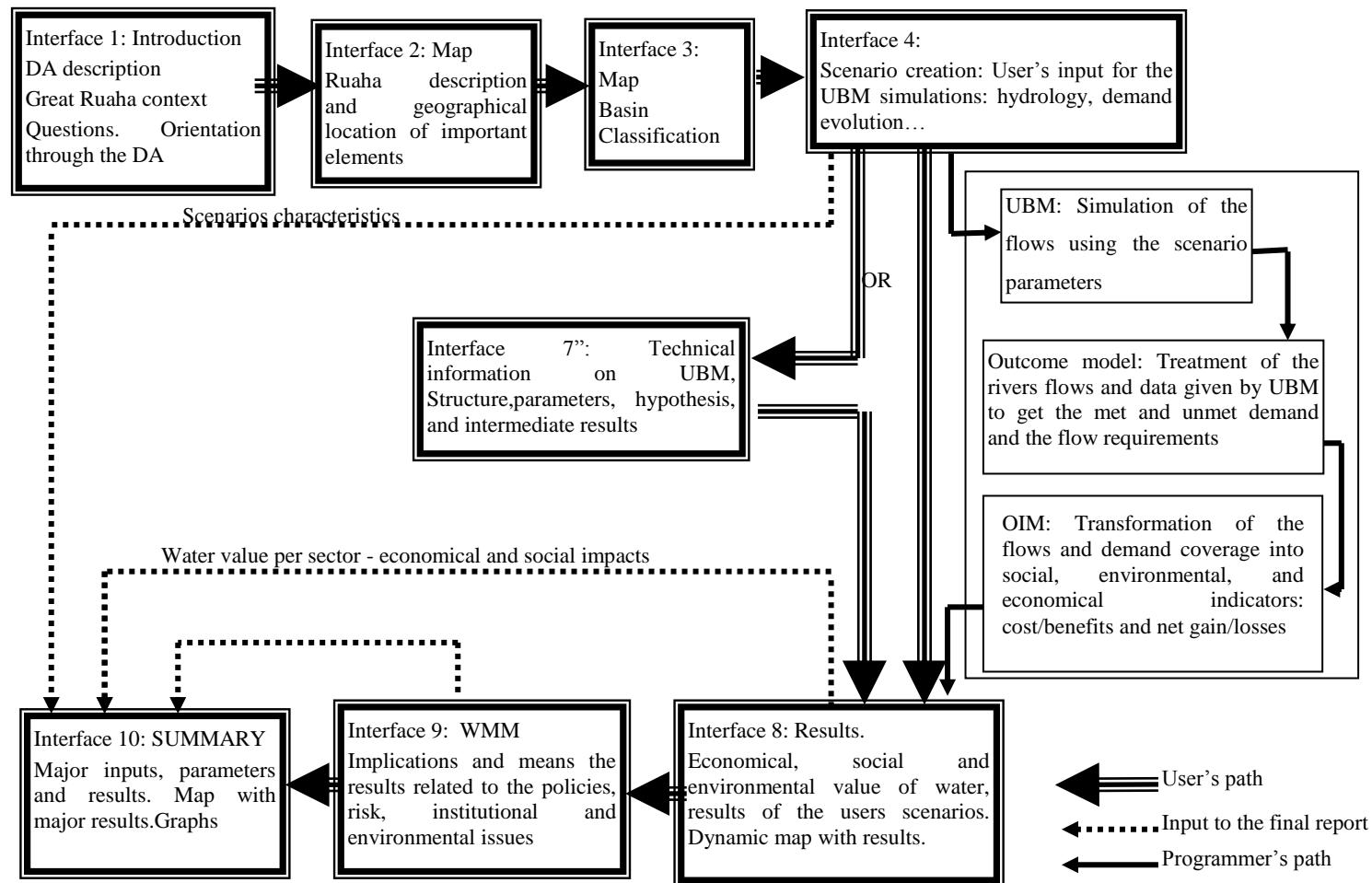
#### **4.4.3. Project meeting**

The project meeting held in November 2002 between researchers from the three project partners and the research associates was important to this PhD research because: i) the final name of the DA was adopted (RUBDA: Ruaha Basin Decision Aid), ii) several decisions were taken concerning the design and the development of the DA, and iii) it was decided at the end of the meeting that the author of the present PhD would join the RIPARWIN project as a research associate in charge of developing RUBDA (RIPARWIN, 2002c). This decision was taken when members of the meeting acknowledged that a substantial amount of work was required in order to achieve the comprehensive tool presented and validated during the steering workshop and that more human resources were needed. The research topic on ‘Hydrological analysis and Decision Aid’ would be divided into two parts; firstly the hydrological analyses, and secondly the development of RUBDA.

Apart from the new name chosen for the DA, discussions were held concerning the WEAP model and the UBM. It was decided that the UBM would be chosen as the hydrological model, and that other modules would be added to cover all the requirements of the DA. It was also decided that WEAP would not be used in the DA because of it was perceived that it would be easier to modify the existing UBM than do the modelling using WEAP.

A diagram representing the structure of the DA was proposed based on the discussions held during the November 2002 meeting (Figure 14). It is composed of ten different components called interfaces. These interfaces take up the ten different components of RUBDA as they were mentioned during the meeting. This diagram would serve as a base of work for the DA structures proposed later during the design and the development of RUBDA.

Figure 14: Schematic of the structure of RUBDA as proposed during the project meeting in November 2002



#### **4.4.4. Was the proposed DA answering the requirements of IWRM?**

The analysis of project documents showed that the DA was meant to perform IWRM. However, the meaning of this statement needs to be explained. Based on a literature review, the present section explains what IWRM requires from a DA before assessing the extent to which the DA proposed by RIPARWIN was in line with IWRM. These clarifications stray away from the project documents-informed analysis contained in the chapter but they are necessary to posit that the proposed DA was actually a DA for IWRM.

The translation of the principles underlying IWRM into requirements for the development of a DA is not straightforward. It is not evident that a DA developed according to these principles will assist IWRM implementation (this is another matter that will be tackled in Chapter 8). One way to establish the requirements of IWRM is by observing how modellers and developers answer requests made by researchers, managers and donors. The call to implement IWRM came because of the recognition that conventional ways of allocating natural resources among competing sectors proved to be inefficient, largely due to a lack of integrated approaches for a comprehensive understanding of river basin characteristics and inter-linkages between components (GWP, 2004). This fuelled the desire to develop and apply integrated tools to support decision-making processes. In other words, DAs are required to perform integrated analysis. Besides, the “integrative” capacity of DAs is commonly used to justify their appropriateness to assist the complex task of implementing IWRM. To do so, DAs must integrate a large amount of information in order to assist decision makers in making rational and informed choices.

What does “integrated” mean?

The core principles of IWRM (Chapter 1) are often criticised because of their vagueness and as a result, the difficulty encountered in translating them into action. To overcome their vagueness and ease their understanding, Cougny (1998) proposed to break down

the core principles of IWRM into simpler “guiding principles”. Cougny (1998) gives a practical way of understanding IWRM through the following principles:

1. Satisfaction of physiological demands
2. Satisfaction of development demands
3. Protection of the environment
4. Prevention of droughts and flooding
5. Link the use of water and land resources
6. Management at the basin scale
7. Polluters pay
8. Users pay
9. Awareness and participation of users
10. Decisions taken at the lowest appropriate level
11. Gender approach
12. Demand management
13. Intersectoral management
14. Apply realistic norms and regulations

Although this list is not exhaustive, managing water resources (or developing a DA) in accordance with it is clearly challenging. Some clues of what such a DA must entail can be obtained from work performed by the Global Water Partnership (GWP), an NGO that promotes the implementation of IWRM. The paper GWP (2000) promotes the use of tools such as models and information systems for water resources assessment (to evaluate resource availability and demand), for communication, as well as for water allocation (according to the economic, social and environmental impacts) and for conflict resolution. A common feature of DAs is that they integrate various technologies and components to increase their capabilities and offer more flexibility. This flexibility is critical, considering the number and variety of tasks they are supposed to achieve.

Various technologies are proposed and used by developers to meet IWRM’s requirements. Geographical Information Systems (GIS) are commonly proposed and are presented here to show how they can fulfil the requirements of IWRM. GIS is a general-purpose technology for handling geographic data in digital form. It is used in DA for spatial integration. GIS brings spatial dimensions into the “traditional” tabular water resource databases, and has the ability to present an integrated view of the world. GIS

can also include other models to combine various social, economic and environmental factors related to the spatial entities of a water resources problem, and make them available for use in decision-making processes (Csillag, 1996). In particular, the visual display capacity of GIS complements the user interface of water resources models, allowing the user to take more complete control of data input and manipulation. Sophisticated graphical user interfaces can provide user-defined triggers, which allow the user to dictate how features will respond to environmental changes, and to construct rules to control the modelling process (Crosbie, 1996). The literature review given in the discussion paper naturally presented GIS as one of the best technologies, and as a result it was suggested for use in RUBDA.

Checking that the different characteristics of RUBDA complied with IWRM principles would be an indication that the design choices were in line with IWRM. Table 8 matches the characteristics of the DA (technology used, type of models, results displayed, etc.) with corresponding IWRM guiding principles. The table shows that all the components of the DA are in line with one or more of the IWRM guiding principles.

*Table 8: Characteristics of the DA compared to the Guiding Principles of IWRM*

Characteristics of the RIPARWIN DA (e.g. technology, type of models)	Corresponding IWRM Guiding principle*
Inclusion of a Database	9, 14
The capacity to generate scenarios and assess the impacts (especially demand driven scenarios)	4, 12, 14
Derives the economic valuation of water	2, 5, 7, 8
Assessment of human basic needs (or domestic needs)	1, 2, 5
Assesses the social impacts of scenarios (often with secondary or tertiary indicators)	1, 9, 11
Assessment of environmental demands and impacts	3, 5
Includes Geographic Information Systems	6
Provides hydrological modelling at the basin scale	6, 14
Ease of use	9
A capacity to simulate effect of new infrastructures	4

\* The numbers correspond to the numerated list of guiding principles given above

#### **4.5. Developing a DA for IWRM: RUBDA v1**

This section analyses project documents produced between April and June 2003. During this period, several meetings were held with local stakeholders and between researchers. The section shows that the design of RUBDA was mainly the outcome of work achieved between project partners and that it was basically designed as an IWRM tool.

Between the November 2002 meeting and March 2003, the design of RUBDA did not progress much. This was mainly because the former research associate in charge of the DA focused on the hydrological analysis. Unintentionally, my involvement in the development of RUBDA represented another increase in the role of IWMI in the RIPARWIN project, especially when considering the promotion of IWRM concepts. Having worked for a year in the South Africa Regional Office of IWMI I had become a proponent of IWRM. To me, IWRM was the most appropriate way of managing water resources. It was therefore without any doubts that I assisted the project with the aim to develop a DA that would serve the needs of implementing IWRM in the Ruaha Basin. The involvement of users in the design process of RUBDA continued through a series of presentations of RUBDA, held between April and June 2003, based on the structure defined during the project meeting in November 2002 (RIPARWIN, 2002c).

##### **4.5.1. Stakeholder meetings**

The draft outline of the DA was presented during a meeting held with a limited number of staff from the Mbarali District Council at Rujewa on 30<sup>th</sup> May 2003, and again two weeks later at the Mbarali District Technical Committee Meeting (DTCM) in front of all the district council's members (13 staff). A third presentation was made in June 2003 for staff from the Ministry of Agriculture, several Food Security Training Institutes (MATI Igurusi, MATI Uyole and MATI Ilonga), SHARDI-Uyole, as well as a representative from the District Agriculture and Livestock Development Office. Although the stakeholders who attended the presentations were enthusiastic about the development of RUBDA, they made few comments or contributions. The meetings were good opportunities to introduce RUBDA to as many Tanzanian professionals as possible, but they did not generate much interaction that impacted upon its design. The



comments about the DA were always very positive: Participants were insisting on the need for a water management DA, yet they did not challenge, elaborate upon or even question the proposed draft DA. During the presentations, the participants were provided with a short report describing the draft DA.

The report stated that RUBDA would help users make decisions regarding the allocation of water between sectors by providing the means to run simultaneously policy driven scenarios, physical changes scenarios and water demand scenarios. RUBDA was made of several models. It was based on a hydrological model (the Usangu Basin Model upgraded) and sustained by an outcome model and water management modules. The report insisted on the fact that the DA had to be a sustainable tool. This meant that it would be user oriented, and developed and owned by the users. To ensure its success, the DA would need to be user-friendly and flexible enough to meet the different users' expectations and designed:

*“to be used by all stakeholders of the basin, especially decision makers, water professionals and researchers. Although not primarily designed for local-level users (being a computer programme in English), there is no reason why the DA could not be demonstrated at the local level as a part of a series of efforts to involve resource users in wider decision-making.” (RIPARWIN, 2003:3)*

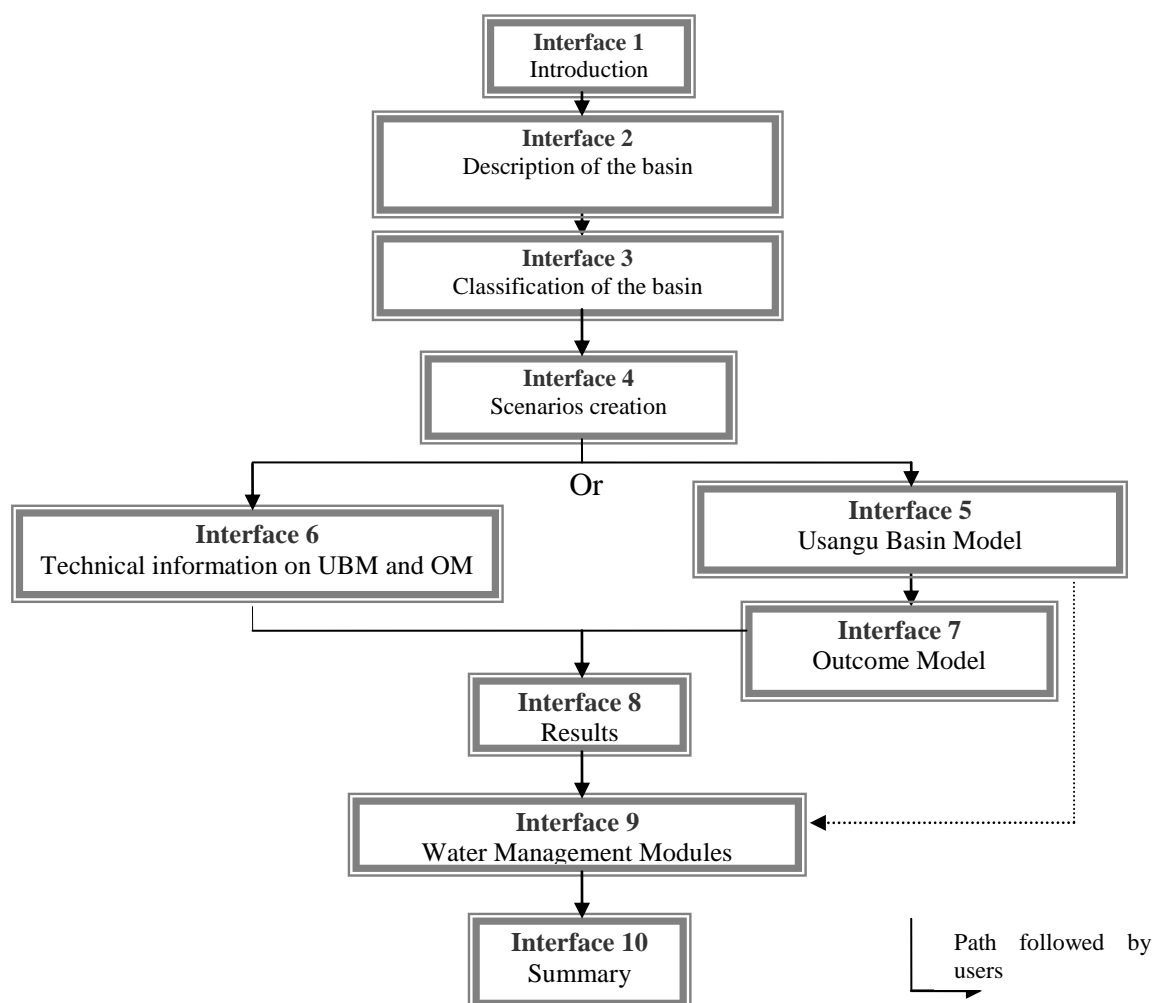
RUBDA would allow the users to go beyond the existing hydrological model (UBM), to involve economic, environmental and social implications in the various scenarios. The aim of the tool was to enhance users' understanding of:

- Water management, competition, use and irrigation productivity under different scenarios
- Water demand of other sectors, a special recognition taken of poor people needs
- Means, potential and impacts of transferring water between sectors on the basis of improved irrigation management and productivity
- River basin characteristics, climatic and allocation means, risks and typologies within semi-arid climate
- Interventions, institutions and participatory processes required to conduct inter-sectoral allocation.

The report also provided a brief description of the tool's 10 windows, called interfaces (see Table 10), which were presented during the meetings. Special attention was given to interfaces 2 and 4, i.e. the description of the basin that was meant to be undertaken using a GIS viewer, and the scenario creation interface respectively. The list of available scenarios was also provided. These scenarios were either physical scenarios (climate, irrigation demand, floodplain behaviour and the hydrology of the swamp) or policy driven scenarios. The policy driven scenarios were described as those directly answering the needs of the decision makers. In the developers' mind, the decision makers had socio-economic objectives and they needed to assess the effects of trying to reach those objectives. To design these policy-driven scenarios, an assessment of the decision makers' objectives had to be made. Then the policies used to reach those objectives would have to be determined. Finally, RUBDA would assess the impact of these scenarios using the hydrological model and the outcome model.

The report's description of interface 5 shows that by May 2003, hydrological modelling per se was not considered critical to the users. Indeed the Usangu Basin Model (once upgraded and updated) would be the core of the modelling but would be an optional user interface. The users would have the choice to bypass interface 6 (the hydrological model still running "behind"). As for the hydrological model, going through the outcome model interface would be optional. The users would instead use a parallel "path" using a separate interface (interface 6; see Figure 15) and access the results interface directly.

Figure 15: Schematic diagram of the structure of RUBDA presented during the stakeholders meetings



As with the presentations, the RUBDA short report did not generate significant contributions from the stakeholders. The draft RUBDA presented during the workshop and in the report recommended the use of the scenario creation component combined with the results (impact of the scenarios) components as the DA's main means to assist decision makers. Defining the way impact would be assessed was therefore critical to fit the needs of decision makers. Following this phase of workshops held with stakeholders, there was a need to define indicators that would allow RUBDA to be useful. The next step of the design of RUBDA was therefore focused on defining these indicators. A temporary list of indicators was determined using the literature review. This list was then presented in South Africa during a meeting with researchers from IWMI, described next.

#### **4.5.2. IWMI researchers meeting**

At the end of June 2003 a trip to South Africa was organised to present the progress achieved on the development of RUBDA. About twenty IWMI researchers and research associates attended the presentation. It was well received and aroused numerous questions. The structure of RUBDA was presented with a particular focus on the economic, social and environmental indicators that could be used.

The indicators were to be generated using the outputs of the hydrological models which produce a large set of flows at different critical points in the basin. The outcome model would use the river flows generated by the hydrological model at particular sites, such as the water available for irrigation and after irrigation, flows entering swamps and wetlands, or at the outlet of the basin. The aim of the outcome model was to use the river flows to generate indicators to address livelihoods, economic or environmental issues.

The indicators that could be used to assess the outcomes of the different scenarios were of three types. The first set were grouped as physical scenarios, while the other two sets, economic and social, were present to explain the trade-off of the assessed water allocation patterns. A list of indicators was presented, and it was specified that the list was non-exhaustive and that the presentation called for comments in order to amend the list of indicators proposed.

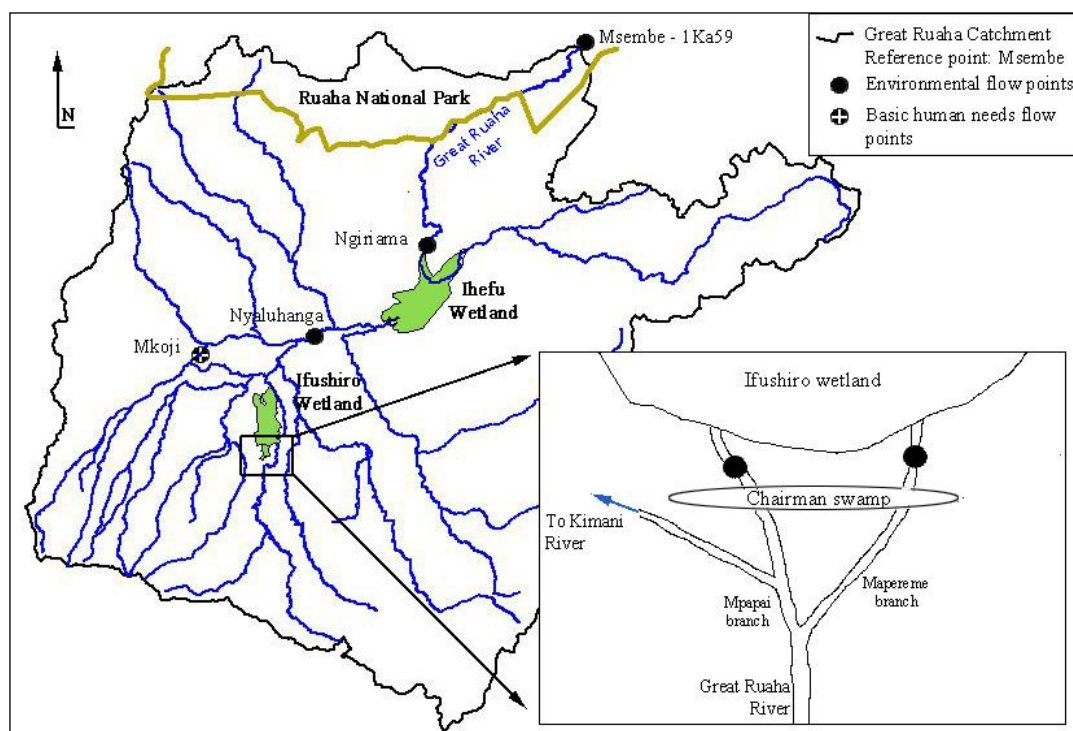
#### ***Physical indicators***

The proposed physical indicators were the flow statistics, composed of three types of indicators (environmental flow requirements (EFR), human flow requirements and irrigation flow requirements), the Wetland size during the wet and the dry seasons, and the areas under different types of land use.

The river flow statistics would be provided for specific locations of particular interest for the users. The users would be prompted about whether the flow requirements were

met or unmet depending on the scenario run. During the presentation, some locations where the environmental flow and human flow requirements would be estimated were also proposed. These locations are presented in Figure 16.

*Figure 16: Map showing the location of environmental and human flow requirement sites*



The location of the sites was determined during discussions held between research associates and based on their experience of the area. But at this point, the list of indicators had not been submitted or even presented to Tanzanian stakeholders. The proposed EFR were defined in five key sites located around the Ruaha National Park (RNP), and the Ifushiro and Ihefu (Usangu) wetlands. The choice of locating a human flow requirement site on the lower part of the Mkoji River was made because of the chronic drying up of the rivers in the area. During the presentation it was mentioned that other sites would be identified later. The key representative sites where water was needed for irrigation were yet to be determined.

### ***Economic indicators***

The input data of the outcome model were the parameters entered into the scenario creation model and the output data of the hydrological model (UBM). Therefore, the

economic impact of the scenarios was to be assessed using the available water and the water used by the different sectors. The proposed indicators were:

- Costs and benefits of rice production both at local and national levels

As rice production is the main activity in the basin, both in terms of quantity produced and incomes, there was a need to consider this as an indicator on its own. Rice production in the Usangu plains and its impact on the local and national economies was one of the research areas addressed by the project. Two solutions to estimate this indicator were proposed: a) the water used for irrigation is the determining factor of production and therefore of the economic implications, or b) the area cultivated and the production determine the quantity of water used and the economic implications.

- Costs and benefits of water used for the hydropower dams

This indicator was described as critical because the Great Ruaha Catchment supplies water to two hydroelectric power stations (Mtera and Kidatu), which generate up to 50% of Tanzania's electricity. The mid 1990s power shortages in the country were partly attributed to the low water flows from the Ruaha River to these hydropower stations (see Chapter 3). It was therefore perceived that the impact of low flows at the outlet of the basin were important at the national level. The high strategic and economic value of the dams required that the decision-makers consider the dams' water requirements when implementing any new water allocation planning. There was a need to evaluate: a) the productivity of water used ( $\$/m^3$ ) by the hydropower dams, and b) the ratio of water provided by the Great Ruaha Catchment. The first, a), could be determined under the RIPARWIN project and the second, b), could be obtained by associating the UBM and a model developed under the SMUWC project that models the Mtera/Kidatu dams.

- Costs and benefits of water utilization in other sectors (e.g. non-rice crops, domestic, fisheries, livestock, brick making, Ruaha National Park)

### ***Social indicators***

The social indicators were described as being heavily dependent upon the available data. A lot was expected from RUBDA concerning the social indicators. Yet these

indicators, it was clear, would certainly be harder to estimate than the physical or even the economic indicators. The social indicators had to be linked to water resources availability. It was proposed that the indicators that could not be related to scenario assessment would appear in the water management modules. The following list of indicators was proposed as a base for this work:

- Number of jobs and population benefiting from the different production activities (e.g. farming, fishermen, bee keepers, National Park)
- Contingent values of water on livelihoods
- Population density (hab/km<sup>2</sup>); This would indicate the demographic distribution as well as local demands for water (domestic, sanitation, etc.). This indicator would be used to determine subsistence flow requirements
- Population under the poverty level
- Human Development Index, based on incomes, life expectancy and literacy (used worldwide to indicate the level of human development and healthiness).

The main issues raised about social indicators were the following:

- There is a need to include water supply management in RUBDA, for instance dams should be modelled in the UBM or appear as solutions to water shortages
- The basic human needs used in RUBDA (human flow requirements) have to be fixed to 150 l person<sup>-1</sup> day<sup>-1</sup> (instead of 25 l person<sup>-1</sup> day<sup>-1</sup>)
- There is a need to modify the structure-diagram of RUBDA: The path that the user must follow in interfaces 5, 6 and 7 is not clear
- The economic indicators are critical in RUBDA. Their development could be inspired from those used in the WATER-IMPACT Model (Rosegrant et al. 2002)
- Special attention has to be given to the flexibility of RUBDA to meet the requirements of all users
- RUBDA has to be a tool transferable to other basins: It must perform integrated analysis of water management in a way that enables other projects to apply it in other countries where IWRM is being implemented.

The issues raised were relevant and corresponded to demands made later during the design phase by other project partners and by some of the stakeholders, so they were

taken on board by the developers. For instance: a) it was decided that a dam model would be developed and included in RUBDA, b) the human flow requirements indicators were raised c) the diagram was modified d) economic indicators (water productivity) were estimated for each sector, e) efforts were done to make RUBDA flexible. The last issue, concerning the capacity of RUBDA to be transferable to other basins was considered difficult to implement because of the importance given to the hydrological modelling in RUBDA: Hydrological models could not be used as they were in other basins. Nevertheless, it was agreed that the methods used for the hydrological modelling and the other modules used to develop RUBDA would be transferable.

The trip to South Africa was also an opportunity to conduct one-to-one interviews with IWMI researchers. One of the interviews was conducted with a social sciences researcher involved on the RIPARWIN project who was keen to discuss and contribute to the development of RUBDA and particularly to the choices made concerning the social indicators. The main issues discussed were:

- The need to develop a Swahili version of RUBDA in order to use the DA with local communities. It was agreed that a Swahili version of the DA would be envisaged by the end of the project
- The need to assess the productivity of water within the different water use sectors, and to link the productivity of water to the number of jobs depending of each water use, to include the concept of “job per drop” in RUBDA
- The aim of modelling the institutional framework was too ambitious
- The water management modules could be included in the description of the basin (interface 2)
- Interface 3 should display GIS information but also provide the current water productivity of the different sectors. The values of the parameters and indicators used in the UBM and the outcome model for the scenario run should be given using the GIS
- RUBDA must consider water supply management as an option for restoring downstream flows. It was agreed that including dams in the UBM would be too time consuming but that they could be proposed as possible solutions. The



RUBDA could, for instance, propose a dam (indicating its size and the time required to fill it) when flow requirements are not met

- It was agreed that the term “environmental flow” was reductive and did not cover livelihoods aspects. For example, the flows needed to sustain Great Ruaha’s wildlife are also the flows that would maintain RNP activity and sustain the livelihoods of people depending on the RNP. The same logic could be applied for the wetlands.

From the nature of the issues raised by IWMI researchers, one general tendency can be noticed: The need to develop a generic tool that takes up current research agendas (IWRM, job per drop, basic human needs, productivity of water, GIS), and that can be used by all stakeholders of the basin, including farmers. Beyond being usable by all stakeholders within the UGRRC, RUBDA had to be sufficiently generic in nature and easily applicable/transferable to other basins across the world.

During my stay in South Africa, some programming work was also achieved. In order to provide more flexibility to the hydrological modelling, the UBM programmes were deconstructed into a set of 10 different small programmes independent from each other. The different programmes were also updated from FORTRAN 77 to FORTRAN 90, to be compatible with Windows XP. This would enable RUBDA to run on the latest computers and would facilitate dialogue between the programmes and interfaces programmed in Visual Basic 6.0. IWMI also agreed to provide software that could be used to develop the GIS viewer (MapObject Lt developed by ESRI). MapObject Lt entailed a number of modules that were used to develop ArcView and Arc Explorer, software that are used by a large number of organisations (including IWMI) to perform GIS activities. Each module corresponds to one or several functionalities and can be combined according to the needs of developers to build a GIS viewer. MapObject Lt was identified as appropriate to develop the RUBDA GIS viewer during a visit at the GIMS offices in Pretoria, representing ESRI for South Africa.

By the beginning of September 2003, the comments gathered in South Africa had been taken into account and the description of the different components of RUBDA was fairly precise. The structure and the different models had been identified, the type of scenarios defined as well as the indicators. The design of RUBDA was mainly the

outcome of work achieved between project partners. The developers, however, were also concerned by the user-oriented features of the DA. It was therefore decided that the next step in the development of RUBDA would be to conduct one-to-one interviews with stakeholders and to arrange “immersion stays” in the different institutions and management bodies. In this way, it was expected, a deep understanding of users’ expectations could be obtained, and real interactions and inputs could shape the design of RUBDA. Here it is important to note that this call for a greater involvement of users had the same origins as that which led to the DA being designed by researchers instead of users: The choice of developing a tool for IWRM which, theoretically at least, implies a bottom-up approach, with stakeholder participation. Therefore, decisions regarding the development of the DA must be taken by the stakeholders themselves. Yet when the decision to conduct one-to-one interviews was taken, most of the decisions regarding the design of the DA had already been taken. The developers nevertheless felt that it was still possible to alter the design as a result of user interviews.

#### **4.5.3. Other activities pursued**

From August to November 2003, the RIPARWIN project research associates were hired to conduct a study for the FAO funded by the Netherlands. This field study aimed to estimate the water productivity, in monetary terms, of the different water uses in the Mkoji Sub-Catchment, one of the sub-catchments of the UGRRC. Results, combined with work achieved on the RIPARWIN project, allowed us to generalise the results obtained at the Mkoji Sub-Catchment level to the UGRRC level. Water productivity estimated per sector was one of the important outputs of the RIPARWIN project and was meant to be included in the outcome model of RUBDA.

#### **4.5.4. Reflection on the design choices made so far**

This section start by summarising the design and technological choices made between 2001 and the end of 2003 before the questionnaire survey started. I also reflects on the participation process.

### ***Summary of design choices***

At the end of 2003, the aim of RUBDA was to define and evaluate alternative water management allocation plans. To do so, it would use knowledge about the nature of the physical processes operating in the system (the UGRRC) to generate prospective scenarios concerning the future behaviour of the system. The hydrological model would be used to extrapolate hydrological data series and to make decisions in relation to planning, design, operation and management of water related issues. These decisions were to be rationally made, informed by the available resources, as well as the environmental, social and economic impact of the various alternative scenarios. To provide users with general information about the catchment, RUBDA would contain a description of the area, a typology of river basins, and some general information concerning a number of themes related to water management (provided in a component called water management modules). It was also proposed that the data and information should be stored in two databases: A tabular database and a geographic database (for the GIS Viewer).

Hydrological modelling was the core of RUBDA. It was decided that an upgraded, updated and more flexible version of the Usangu Basin Model developed by the SMUWC project would be used for the hydrological modelling. To go beyond the hydrological modelling, RUBDA would contain an outcome model. The outcome model would assess the environmental, social and economic impacts of the scenarios. The outcome model had to transform the daily river flow results into social, environmental and economic indicators.

Hydrological models were recompiled using FORTRAN 90 and interfaces written in Swahili. VISUAL BASIC 6.0 was chosen to programme the interfaces due to its capacity to easily generate “windows-like” interfaces and because it was the programming language used by programmers of the Sokoine University of Agriculture of the Soil and Water Research Group (one of the three RIPARWIN project partners). Although FORTRAN and VISUAL BASIC were rather “old” programming languages, their use would facilitate uptake and maintenance of RUBDA by Tanzanians themselves.

### ***Reflecting on the participation process so far***

As mentioned earlier, most of the contributions made to the design of the DA originated from researchers themselves. It was the case that while researchers were defining and designing what the DA would be, they were promoting the need to design a tool that would satisfy users' needs. Ultimately, however, that would have surely meant involving users in the development of the tool and not relying on researchers' opinions of what the DA had to be. Higher expectations raised during workshops and meetings, however, had progressively made users' involvement more difficult.

RUBDA had been designed during the first phase as a research tool built for integrated analysis. It was based on a hydrological model, comprised several models and had to assess the physical, social and economic impacts of scenarios run by modifying water allocation choices and climate parameters. Developers and project partners believed that it was the answer to users' needs, based on the assumption that Integrated water resources planning and management required that a large amount of information is gathered and brought together in a framework capable of undertaking an integrated analysis.

Furthermore, impact assessment had to be done using economic and social indicators, in order to inform sustainable water allocation decisions. This seemed to imply that water managers were relying on these economic and social indicators to take sound decisions. Which they did not do (see Chapter 3).

In different documents (e.g. RIPARWIN 2003) it was mentioned that the success of RUBDA would depend upon the successful involvement of all stakeholders. The number of potential users grew higher after each meeting and workshop. During workshops, most participants appeared enthusiastic about a tool that they imagined would solve all their problems. For instance, towards the end of June 2002, the tool was to be used by researchers and by all the stakeholders involved in water management in the studied area, from district council members to farmers themselves. A call was even made by IWMI that RUBDA would be applicable in other basins across the world. This

was to be achieved by undertaking intensive participation, and by developing a user-friendly and flexible enough DA to satisfy all potential users.

#### **4.6. Strengthening participation: a questionnaire survey**

Semi-structured interviews with key informants were conducted using a questionnaire survey between December 2003 and June 2004 (See Appendix A). The interviews were intended to collect inputs from the potential users of RUBDA that the workshops had been unable to provide. The lack of qualitative information collected concerning the needs of users during the first phase of the development of RUBDA was the main motivation for the developers to conduct the new interviews. The interviews were therefore perceived by the developers to be critical during the development phase, in order to ensure the success of RUBDA. The interviews were critical to this research because the analysis of the information collected during the interviews should provide insights into the requirements and priorities of the informants and to explore whether RUBDA would be designed to answer these requirements.

##### **4.6.1. The structure of the questionnaires**

The guiding principle in the stakeholders' interviews was to get informants to talk about what was important to them concerning water management and to use information to help design RUBDA. Parts of the questionnaire asked the informants to directly describe their requirements concerning the components of RUBDA. Thus, the informants had to review and comment upon lists of scenario input parameters, results indicators and to indicate the way these results should be displayed. Other questions did not concern the design of RUBDA directly, but instead sought to gain insights into the informants' understanding and perception of the management of water resources. These included informants' perceptions about what were important water management objectives and the options (or actions) that ought to be implemented to reach those objectives. Understanding informants' "visions" of what could be achieved in the UGRRC when managing water resources was meant to be a complementary source of information for the design of RUBDA. The filled questionnaires were sent by mail or email (when possible) for validation by the informants before being analysed.

The first step of the interview phase was the identification of key organisations and informants to be included in the questionnaire survey. The questionnaire was organised into six themes around which the questions were developed. The themes included:

1. The role/mission of the informants and of his/her organisation;
2. Existing/missing sources and types of information used to execute his/her mission;
3. The informant's ability to use computers and the characteristics of the computer used;
4. Identification of water management objectives and options;
5. Identification of indicators to include in RUBDA and their display (units etc.);
6. Scenarios that need to be run in RUBDA.

In addition to the major themes around which the questions were organised, the interviews provided the opportunity to discuss issues related to the DA in general, and to the management of water in the UGRRC. The informants were asked to examine the lists of objectives, options, indicators and scenarios, to choose those that they felt were critical, and to rank them based on their importance. They were also asked to consider a list of organisations being interviewed during the survey, and to rank their importance as actors in the management of water resources and as potential users of RUBDA. The questionnaire thus evolved during the interview phase since the list from which informants had to choose objectives or options changed slightly. This iterative approach was a possible source of bias and therefore reduces the possibility to directly compare results between informants' responses.

#### **4.6.2. Selection of the key informants**

For the questionnaire survey, identification of the key informants was based upon the knowledge gained during the first phase of RIPARWIN. To increase the survey's practical feasibility, a number of informants were selected from the long list of actors that had attended the various workshops held during the first phase. Although only a limited number of actors were selected, the list aimed to cover a balanced set of

interests and positions among the targeted users of RUBDA. The list of key informants interviewed is given in Table 9.

*Table 9: List of key informants interviewed during the questionnaire survey.*

	<b>Institution</b>	<b>Position</b>
1	Ruaha National Park	Acting Chief Park Warden
2	Ruaha National Park	Park Ecologist
3	TanESCO	Mtera Dam Manager
4	TanESCO	Engineer
5	RBWO Iringa	Director
6	RBWO Iringa	Vice Director
7	Ministry of Water and Livestock	Iringa Regional Hydrological Officer
8	Ministry of Agriculture (MATI Igurusi)	Principal of MATI Igurusi
9	RBWO Rujewa	Manager
10	Mbarali District Council	Water Engineer
11	Mbarali District Council	Administrative Officer
12	Mbarali District Council	Irrigation technician
13	Mbeya Rural District Council	DALDO Officer

Firstly, a review of the existing decision-making structures (see Chapter 3) allowed the identification of those with formal positions in the management of water resources. The RBWO and the Mbarali District Council were chosen because they were the two main organisations involved in the management of water resources in the study area. These two organisations were also the main targeted users of RUBDA and several of their members were therefore interviewed. The RUBDA end-users were chosen among the stakeholders that had been involved in the meetings and workshops organised by RIPARWIN (see sections 4.3. to 4.5. ) as those that were potential direct users of RUBDA. It meant that stakeholders involved in the management of water resources in the UGRRC that were not part of the RBWO or the Mbarali District Council were perceived as stakeholders that would benefit from the use of RBWO by the end-users but not as end-users themselves. This narrowing down of potential end-users of RUBDA was part of an effort made to improve the design of RUBDA. The aim was to focus on certain targeted users.

Secondly, efforts were made to cover the structures that represented the different interests that existed within the water management framework in place in the study area. The director of the Ministry of Agriculture Training Institute in Igurusi was also part of the survey, for he was considered to be a good representative for the Ministry of Agriculture. In addition, he was particularly interested in RUBDA and keen to get involved in its design. The different ministries had representatives sitting in the District Councils, and thus some members of the Ministry of Agriculture from the Mbarali and Mbeya Rural District Councils were interviewed. The Iringa regional hydrologist from the Ministry of Water and Livestock was interviewed because of his important role in the delivery of water rights and in the collection of hydrological data. From 2005, the RBWO was in charge of achieving the collection of hydrological data and of providing hydrological expertise for the delivery of water rights. The chief park warden and the park ecologist of the Ruaha National Park (RNP) were interviewed because the Great Ruaha River was the major source of water for the RNP. The TANESCO manager of the Mtera Dam was interviewed, because the decrease in dry season flows had greatly affected the electricity produced by the Mtera and Kidatu Hydropower Dams, located downstream of the RNP.

During the questionnaire survey, informants were asked to identify other important actors that were not participating in the questionnaire survey. In this way, the Mbeya Rural District was identified as an important stakeholder. A small part of the UGRRC was located within the Mbeya Rural District and so it was decided to interview one of its council's members, which was the representative of the District Agricultural and Livestock Development Office (DALDO).

Some of the planned interviews could not be conducted. For instance, the chairman of the NGO Friends of Ruaha – which is actively involved in the protection of the Ruaha National Park and the Usangu Game Reserve – did not desire to answer the questions because the development of a DA for the management of the water resources did not appear to him to be as important as the restoration of flows in the Great Ruaha River. The same can be said for some members of the Mbeya Rural District Council. Although they did not refuse the interviews, instead they cancelled and postponed the meetings on several occasions until they were removed from the list. Their lack of interest in RUBDA, or at least in the questionnaire survey, can be explained by the small part of



the district which was actually located in the GRRC. Furthermore, the Mbeya Rural District is located in the upstream part of the GRRC, which reduces their interest in downstream water shortages significantly.

A much more problematic matter was that the director of the RBWO, who had repeatedly urged the RIPARWIN project to deliver RUBDA and who had shown enthusiasm for RUBDA on several occasions, did not make time to answer the questionnaire. The interview was postponed on several occasions, and when it was finally organised, the interviewee was called for an urgent Ministry of Water and Livestock meeting in Dar es Salaam. The director proposed to fill in the questionnaire on paper and to send it by e-mail, but only answered the first few questions. To overcome this, the questionnaire's developer decided to conduct an immersing stay within the RBWO, to get information concerning their requirements. Yet the director had to travel abroad for another urgent meeting during this visit. His enthusiasm for RUBDA cannot be questioned, but the difficulty of getting him to participate in the design of RUBDA had significant impacts upon its development. As one of the main targeted users, perhaps the most important, his needs were important to the process. On several occasions, much later in the development of RUBDA, the director was involved and his inputs led to significant changes being made to the DA. These inputs and changes are examined in Chapters 5 and 6.

#### **4.6.3. Analysis of the questionnaire survey**

##### ***Role of the informants and of his organization***

The informants from the district councils and from the RBWO were especially interesting to interview because they were all decision makers, in charge of implementing the control and the regulations of water use, and in contact with the users to a certain extent. Table 9 lists their positions and main responsibilities. The informants from the RNP and TANESCO were involved in activities linked to their organisations and not to the management of water resources in the UGRRC per se. Yet it was important to understand their activities and requirements so that RUBDA could benefit them either directly if they were to use RUBDA, or indirectly, if RUBDA could run

scenarios and assess their impacts using indicators that were relevant for them as downstream water users.

The main tasks undertaken by the informants from the district councils and the RBWO concerned the collection of hydrological data, and more importantly, the delivery of water permits and the definition and implementation of regulations (see Chapter 3). They also acted as mediators for conflict resolution between users, and as trainers for water management (irrigation, WUA creation). Although RUBDA in the first instance seemed irrelevant for such activities, it could have been used to assess the impact of certain water uses and could offer a lot of information concerning the design of irrigation schemes, methods to increase the productivity of water, or even about how to develop water user associations (WUAs).

The main tasks achieved by the informants that were of interest for the design of RUBDA were the delivery of water rights, the control of water uses and the design of regulations and restrictions by the director of the RBWO with the Water Board. The definition of water allocation strategies or water allocation plans was not mentioned as an activity by the informants. They declared that their activities were mainly “limited” to the delivery of water rights which depended upon downstream impacts and the implementation of restrictions during the dry season.

Table 10: Tasks/missions of the informants within their organisations.

Position	Role / mission
DALDO Officer Mbeya Rural District Council	Part of the water rights (WRs) “panel” Assessment of the detrimental effects of water abstractions Advise extension officers on design of irrigation schemes and intakes
Irrigation Technician Mbarali District Council	Technical support to design and intakes of irrigation schemes Part of the WRs “panel” Registration of water user associations (WUAs) Advise farmers on agricultural practices
Administrative officer Mbarali District Council	Administrative tasks Assist district commissioner on policy implementation Part of the water rights “panel” Mediator for conflict resolution between water users
Water Engineer Mbarali District Council	Part of the water rights “panel” Design and follow-up of small water infrastructure projects In charge of villagers trainings
Manager RBWO Rujewa Sub Office	Part of the water rights “panel” Data collection (river flows, water uses) Control of abstractions Implementation of regulations Contact person for water users from GRRC Part of the Basin Water Board
Principal of Ministry of Agriculture Training Institute of Igurusi (MATII)	Administrative tasks Training of extension officers
Iringa Regional Hydrology officer Ministry of Water and Livestock (Position is now moved to RBWO)	Part of the water rights “panel” (Assessment of water available and downstream impacts) Data collection
Officer in charge of Water Permits Department RBWO Head Office	Leads the water rights “panel” (processing) Follows WUA creation and running Implementation of regulations In charge of water users training
Director RBWO Head Office	Part of the water rights “panel” Part of the Rufiji basin Water Board Define Regulations and restrictions
Mtera Dam Manager TANESCO	Management of Mtera Hydropower Dam Controls electricity production and dam storage
Park Warden Ruaha National Park (TANAPA)	Management of the park Establish ecological research and monitoring programs Raise conservation awareness among communities etc
Park Ecologist: Ruaha National Park (TANAPA)	Monitor Great Ruaha and Mzombe Rivers flows Ecosystems “management” etc

## ***Existing and missing information***

The aim of these questions was to understand what were the needs of end-users in terms of data and information and therefore the type of data RUBDA had to generate.

### ***a) Sources of information***

To understand how decisions were taken and to collect data to be stored in the RUBDA databases, informants were asked to reveal what types of data they used and the methods by which these data were collected. In fact, there were few data *per se* used to take decisions apart from the available data were river flows from the existing and working gauging stations, and very little GIS data (produced by the GIS lab in RBWO Iringa). The informants repeated that they were relying a lot on the information collected during training, workshops and from instructions and manuals coming from projects or ministries. A lot of the data and information available (guidelines, guides of good practices, etc.) were produced by donor funded projects (such as SMUWC and World Wide Fund for Nature).

### ***b) Missing information***

Identifying the data and information that the informants were missing to achieve their role and mission was important. The DA would have been designed to produce that information. Several informants revealed that there were data or information that were missing and negatively affecting their activities and tasks within their organisations. This was especially the case for the director of the Water Rights Department of the RBWO. The missing data/information mentioned were given freely and were as follows (in brackets: number of informants who mentioned the information as missing):

- Effectiveness of water rights (2)
- Intakes abstraction during the dry season (2)
- Environmental flows of the rivers (1)
- Water available in the rivers (1)
- Land use planning (1)
- Hydrology on the Ihefu wetland (1)

- Effectiveness of enforcement efforts/regulations (1)
- Economic contribution of agricultural activities in the fans and the wetlands (1)
- Social economic analysis of the upper catchment (1)
- Mitigation measures of the on-going irrigation projects (1)
- Land use for each district (1)

The only informant to mention that socio-economic data were missing was from the RNP. The actual managers and decision makers from the RBWO and from the two district councils did not perceive this information to be missing. Because they were not available, these managers seem to have felt that socio-economic data were not important. Data pertaining to environmental flows of the rivers and the hydrology of the wetlands were mentioned by various participants in different ways. Yet they all represented organisations that needed to know how downstream wetlands worked in order to manage the upstream part of the UGRRC.

As described above, the informants did not have much to say when asked about information and data (either existing or missing) that they used to perform their tasks. This is not to say that they were reluctant to talk about this issue, but more about the fact that most of the informants did not use much data when taking decisions. The activities for which they required data and information mainly concerned the training of villagers and the design of irrigation schemes. The phrasing of the question had to be altered in most of the cases to get the informants to talk about missing data. Rather than asking them what data were missing for achieving their tasks, they were asked more generally about what data and information were lacking for the management of water resources in the UGRRC. This indicated that decisions were not taken in a rational, optimal way, based on sound data. All informants felt that it was important to generate the missing data to properly manage the UGRRC. However none declared that this was important for their own management activities. The question remains, therefore, of how these decision makers actually take decisions regarding the allocation of water and its uses? Are they simply implementing short term restrictions during seasonal shortages? Is anyone managing water resources and/or are the informants not the ones doing it?

### ***Computer availability and informant's ability***

One of the six themes around which the questionnaire was built concerned the availability of computers in the targeted organisations and the capacity of the informants to use these computers. The first aim was to know if there were computers on which to run RUBDA within their organisation, and also to establish their operating systems as presented in Table 10.

*Table 11: Computer availability and operating systems.*

Operating system	Windows 98	Windows 2000	Windows XP	Total
Computers available	6	8	6	20

Apart from the Iringa regional hydrologist who did not have access to a computer, all the key informants had access to one or more computers. In total, 20 computers were identified. The computers were all running on Windows but using different versions. This implied that RUBDA would necessarily need to be compatible with the three versions of Windows. The latest version, Windows XP, was perceived to be the most problematic because of the risks of incompatibility between Windows XP and the FORTRAN programmes used for the hydrological modelling.

The informants were then asked how comfortable they were concerning the use of these computers (Table 12). The aim here was to assess their capacity to run RUBDA. Among the 12 informants only one declared that he was not comfortable with computers.

*Table 12: Informant's perception of their ability to use computers and RUBDA*

	Not comfortable	Fairly comfortable	Comfortable	Total
Informants' perceptions of computers use (and RUBDA)	1	3	8	12

It is important to note that although Table 12 presents the informants' perceptions of their capacity to use computers this might not reflect their actual level or ability.

## ***Identification of water management objectives and options***

The identification of the water management objectives and the options selected by the informants to achieve these objectives was an important part of the questionnaire. It aimed to reveal a lot about the informant's view of the problems and solutions related to the management of water resources in the UGRRC.

### ***a) Water management objectives***

Informants were asked to review a list of water management objectives. They were requested to comment upon the list, to remove or add new objectives, then to choose the three objectives they perceived as having the highest priority. The list of objectives proposed to the informants was as follows:

1. Management of water distribution in the dry season;
2. Increase/decrease of irrigation abstractions and activities;
3. Development of rainwater harvesting;
4. Education of water users;
5. Realistic allocation of water rights (WRs); devolution of WRs to sub-catchment level;
6. Conservation of environment (wetlands, flora, fauna...);
7. Ensure water for hydropower stations downstream;
8. Ensure water for RNP;
9. Improvement of water productivity in irrigation, re-designing intakes to allow for water sharing;
10. Development of water supply infrastructure (dams);
11. Clean water accessible at a short distance for domestic needs;
12. Ensure water for livestock.

Most of the informants said that the objectives were fine and that they had no comments to make. The few comments made concerned objective 2. The participants were intentionally given the choice between two possibilities; either to increase or decrease irrigation abstractions and activities. None of them chose to increase these, not even the officers from the Ministry of Agriculture. Interestingly, at this time, the Ministry of Agriculture had made a call to increase irrigation in Tanzania (see Chapter 3).

Four participants asked to add objectives to the list. The added objectives were: “alternative and supplementary crops”, “water for the Usangu wetlands”, “training for technical advisers” and “equal share of water to resolve conflicts”. Only one objective was described as not useful (objective 10).

*Table 13: Ranking and scores obtained by the objectives during the questionnaire survey*

Objectives **	Group 1 Decision makers						Group 2 “users”				Number of times ranked	Weight* Group 1	Weight* Group 2	Weight* Total
	MRDC	MDC	MDC	MDC	RBWO SO	RBWO HO	RNP	RNP	TANESCO	TANESCO				
1.	2				1	1					3	<b>8</b>	0	<b>8</b>
2.											0	0	0	0
3.			3								1	1	0	1
4.		1			2	2	3	3			5	<b>7</b>	2	<b>9</b>
5.		2							3	2	3	2	3	5
6.	1		2				2	2			4	<b>5</b>	4	<b>9</b>
7.						2			1	1	3	2	6	<b>8</b>
8.						3	1	1			3	1	6	<b>7</b>
9.	3	3	1		3				2	3	6	<b>6</b>	3	<b>9</b>
10.											0	0	0	0
11.						1					1	3	0	3
12.				3							1	1	0	1

\* weights are estimated by giving points to ranks (rank 1 = 3 pts; rank 2 = 2 pts; rank 3 = 1 pt)

\*\* the objective’s are listed in full in the text above this table

To rank the importance of the objectives, the participants were asked to choose the most important ones and to rank them from 1 to 3, rank 1 being the most critical objective. The objectives chosen by the participants and their ranks are given in Table 13. If an objective was ranked, it was perceived by the informant to be an important objective. To take into account the ranks given to each objective, weights of the objectives were estimated by multiplying the number of times the objectives were ranked as first, second and third (rank one was multiplied by three, rank two by two, and rank three by one). The numbers of points obtained by each objective represented its importance. The calculation of the weights was done for the participants from the district councils and RBWO (Group 1) and for the participants from RNP and the electricity company,



TANESCO (Group 2). The first Group represented the water managers directly targeted by RUBDA, while the participants of Group 2 represented water users. Two participants from Group 1 were not included in the table because they did not answer this question.

The main observations regarding the water management objectives are as follows:

- The management of dry season flows (objective 1) gets the highest score among decision makers. This was the most discussed matter, for dry season flows were at the core of the area's water problems;
- Educating water users (objective 4) was also given the highest priority, especially from decision makers;
- Delivering water rights that reflect the water availability in the rivers (objective 5) was not a priority for decision makers. This was surprising because the informants were all part of the panel in charge of delivering water rights. Even the RBWO officer in charge of the delivery of Water Rights did not consider this to be important. This seems to mean that Water Rights were not seen to be a way of managing water resources. The officers from the electricity company were the only ones counting on Water Rights to solve their problems;
- The protection of the environment (objective 6) was ranked as a priority for a lot of participants including the decision makers themselves. Naturally the two RNP participants contributed to increase the weight of this objective. But even the DALDO district officer gave high priority to the protection of the environment, even though he represented the Ministry of Agriculture;
- Improving the productivity of water (objective 9) obtained the highest weights, just behind the management of dry season flows. It was mentioned by more participants than any other, and was also ranked as one of the most important objectives for decision makers. Productivity here must be understood in terms of production and not in economic terms;
- Getting water to flow downstream to the hydropower dams (objective 10) received a fairly high weight, but this high score was mainly due to the answers given by the two participants from the electricity company (TanESCO). Only one decision maker from the RBWO head office in Iringa ranked this to be important. This is probably due to the fact that the Mtera Dam is located not far from Iringa while the other decision makers interviewed were located within the upper parts

of the catchment where the dams seem very far away, and were thus not perceived to be high priority water uses.

The views and interests that are described and analysed here represent those of specific stakeholders and are not representative of the UGRRC basin stakeholders in general. Indeed they represent the main targeted users of RUBDA and a few representatives of the downstream users. Nevertheless, the results of this analysis are of importance to this research because they allow comparison of the tasks and roles of the informants within their organisations, and of their views of what was important for the management of water resources in the UGRRC.

### **b) Options to reach water management objectives**

The informants were asked what they thought were the options (and who should implement them) to achieve the stated water management objectives. This part of the questionnaire was answered only by seven informants. The participants were asked to speak freely and to mention any option they felt could help to reach the objective they had selected. Because most of the options were chosen by the participants during the interviews, the options presented in the table are not all at the same operational level.

Table 14 firstly reveals that water user associations (options 1, 15) are perceived to be a viable solution to manage dry season water distribution (objective 1), a means to educate water users (objective 4), and to provide water for domestic needs (objective 11). Secondly, rainwater water harvesting and Charco dams to harvest rainwater (options 16, 17, 18, 20) were repeatedly cited as appropriate actions that would assist the fulfilment of almost all the selected objectives. This was surprising because rain water harvesting was never really mentioned during the meetings and workshops. Thirdly, the options relating to a reduction of the irrigation demand (options 10, 11, 12, 13) were the options selected the highest number of times. Thus, improving the irrigation schemes' infrastructure, shifting to less demanding crops or even reducing the irrigated area should enable the fulfilment of objectives 1, 4, 6, and 9. Fourthly, conservation of water sources (option 2) was also perceived to be a means to meet objectives 1, 9, and 11. Fifthly, the options that related to the delivery of Water Rights, their review and their use to manage water resources (options 6, 7, 8, 9) were not

perceived to be important options. This confirms that Water Rights are not perceived to be a way of managing water abstractions. Indeed, the decision makers did not count on these actions to meet the objectives.

*Table 14: Options selected to meet the objectives selected by the informants*

	Objectives (see Table 12)					
Options	1.	3.	4.	6.	9.	11.
Involvement of all stakeholders in Apexes <sup>14</sup> and water user associations	X					X
Conservation of water sources	X				X	X
Introduce by-law for water sources conservation						
Elaborate land use plans			X			
Set aside livestock grazing areas						X
Review available water resources	X					
Review water rights to conform to available water resources						
Involve water users in allocating water rights						
Develop water monitoring to ensure abstraction according to water rights			X		X	
Improve water management at the irrigation scheme level	X		X			
Improve irrigation infrastructure					X	
Produce low water demanding crops				X		
Use conservation agriculture practices			X			
Reduce irrigated land				X	X	
Encourage formation and strengthening of WUA			X			
Stakeholders to be trained on rain water harvesting		X	X	X		
Construction of Chaco dams	X	X				X
Government should direct funds to construction of water harvesting infrastructure		X				
Government should increase experts to train farmers on water harvesting techniques			X			
Farmers should be encouraged to contribute to build dams	X	X				
Uprooting water depleting trees and planting indigenous trees						
Develop use of groundwater						

The informants were also asked if in the list provided there were counter productive options to reaching the chosen objectives. None of the participants selected any. They were also asked to explain who should be in charge and who should be involved in the implementation of the selected options. Participants gave very general answers. The Ministry of Water and Livestock, the RBWO (as the regulatory board), the district councils and the Ministry of Agriculture were the organisations designated as the ones

<sup>14</sup> Apex Water Users Associations are Sub-Catchments Water User Association (see chapter 3)

that should be in charge of the options' implementation. The informants also mentioned several times that the organisations in charge had to involve the water users. Financial and technical problems were cited to be the main obstacles to the implementation of the options.

### ***RUBDA Scenarios***

Informants were presented with the following list of nine scenarios and asked to review and amend the list:

1. Evolution of rainfall: the user defines a sequence of rainfall based on existing data;
2. Input at the rainfall stations: the user imports new rainfall data;
3. Input at the gauging stations: the user imports new flow data;
4. Modification of the irrigated abstraction rates and area served;
5. Modification of the irrigation efficiency;
6. Evolution of water abstracted for irrigation;
7. Modification of the hydrology of the Western floodplain (mainly using the threshold value);
8. Modification of the Ifushiro wetland area and flow routing characteristics;
9. Policy driven scenario to assess the impact of policies that would be implemented to reach the water management objectives.

All the participants declared that the proposed scenarios were fine and that the assessment of their impacts would assist the management of water resources in the UGRRC. Scenarios 1, 6 and 9 were those designated as the most useful, especially for the informants from the RBWO. Those informants dependent upon the Ministry of Agriculture (from Mbarali District Council and MATI) insisted that scenarios 5 and 6 were important and that modelling the irrigation water demand was critical.

Some new parameters to define scenarios were also suggested by various participants:

- Supply management, using dams, to “boost” irrigation;
- Rain water harvesting technologies should be taken into account and modelled;
- Access to water supply for domestic needs for all the population;
- Decrease livestock and area for livestock in land use plans;

- Evolution of household income or poverty level;
- Evolution of the population in the basin;
- Evolution of the number of water users and of migration;
- Double cropping in irrigation.

### ***Identification of outcome indicators and display of results***

The respondents were asked to review the following list of proposed outcome indicators, comment on their usefulness and to amend the list where necessary. Indicators here should be understood as outputs of RUBDA, intended to transform raw results generated by the different models into a more understandable and usable form. Reviewing the indicators was one of the main objectives of the questionnaire survey. It was seen by the developer as one of the main contributions that had to come out of the interviews and critical for the usefulness of RUBDA.

1. Water available at the basin level;
2. Water available per capita;
3. River flows at key points;
4. Sectoral water uses at the basin level;
5. Environmental flow requirements – during key months;
6. Subsistence flow requirements;
7. Irrigation flow requirements;
8. Wet and dry season size of the wetlands;
9. Area under different land uses;
10. Costs/benefits of rice production;
11. Costs/benefits of water used for the hydropower electricity production;
12. Costs/benefits of water utilisation in other sectors;
13. Percentage area under different land uses;
14. Population benefiting from each water use;
15. Maximum wet season abstraction rate (estimated to be about  $50 \text{ m}^3\text{s}^{-1}$ ).

Aside from indicator 11, which was described as not useful by one respondent, all the indicators were described as appropriate for aiding decisions. Indicators 1, 2, 7, 9, 10, 14 and 15 were those described as most useful. These indicators concern the water available at the basin level and per capita, the irrigation flow requirements (in other

words the irrigation demand), the maximum wet season abstraction rate, the land use, the cost/benefits of rice production and the population benefiting from each water use. Each indicator was mentioned as important by only one informant. Some informants asked to add some new indicators to the proposed list. Four new indicators were added: dry season abstraction rates, conservation of water resources technologies, efficiency of valley bottom agriculture, and level of education of the population.

One informant was especially keen to discuss environmental and irrigation flow requirements. As a member of the Mbarali District Council, the informant insisted on the fact that getting river flows in specific locations would be of great use. It was not the notion of flow requirements *per se* that was seen as important but rather the river flows themselves. The river flows were to be given upstream and downstream of the wetlands, and downstream of the main irrigation intakes on the Mbarali, Great Ruaha, Kimani Ndembera, Little Ruaha, Mswiswi, Mambi and Lunua rivers.

Regarding the units and display of these indicators, all the informants asked to get river flows in metres cubes per second, area in hectares, agriculture production in tonnes, and population in habitants. The informants declared that the indicators were to be given at the sub-catchment level except for the cost benefits of rice production that was to be given for the whole UGRRC. The respondents also declared that the most useful display would be in tables or maps if feasible.

A close look at the indicators proposed and added by the informants reveals a certain vagueness in their perception of the entry parameters that the users would be able to modify to define the scenarios, and of the output (indicators) parameters that they would use to assess the impacts of the scenarios. This vagueness is linked to the way the scenarios and indicators were presented by the developers during the interviews. Indeed, at the time of the questionnaire survey it was not entirely clear in the developers' minds what the input and output parameters of RUBDA would be. This is a direct result of the design phase of RUBDA, during which the aims and functionalities of RUBDA were not defined precisely. RUBDA had to perform an integrated analysis and to assess the scenarios using a very wide range of physical, economic and social indicators. When the questionnaire survey was conducted it was clear that RUBDA would be based on a hydrological model. But the capacity of RUBDA to model the socio-economic dimensions in parallel to modelling of the hydrology was not very well defined at this

point. The extent to which the economic and social dimensions would be modelled within the scenarios (part of the scenarios input and output parameters), or within only part of the scenarios assessment components (part of the outputs only), was not clear in the developers' minds. This vagueness is apparent by the way the indicators were described and therefore in the answers given by the informants. Thus, most of the indicators can be understood either as inputs or outputs of the model. For instance, the water available at the basin level, the sectoral water uses, the maximum wet season abstractions, or even the education of the population, could be parameters modified by the users when they define the scenarios, or used as indicators to assess the impacts of scenarios.

At the end of the survey the author was satisfied because the indicators proposed were accepted. Such a validation, without (almost) any changes to the indicators proposed, can be interpreted in different ways. Indeed, it can be seen as an indication that the users did not know precisely what they wanted or that they did not perceive RUBDA to be a tool to aid the decisions they take. Rather, the interviews show that they understood it to be a tool to enhance their general understanding of the UGRRC.

### ***Summary of the questionnaire survey outputs***

Conducting the questionnaire survey provided a good opportunity to understand the users' activities and demands regarding RUBDA. The survey also forced developers to narrow down the number of users targeted by RUBDA (identifying who were the main targeted users in order to reduce the number of interviews). Analysis of the survey enabled the most useful indicators and scenarios to be included in the DA to be identified. The survey also gave information about how to display the results and their units. This could have a significant impact on the use of RUBDA in its presentation of results in an intelligible way for users. It is important to note that during these interviews the informants requested to receive results at the sub-catchment level and in river flows at specific locations upstream and downstream of the irrigation schemes and the wetlands.

The analysis of the informants' responses reveals that a gap existed between what informants declared to be important for the management of water resources in the basin,

and their actual activities and missions. The way that water rights were perceived by decision makers is a good example of the gap between discourse and facts. All decision makers interviewed were members of the water rights delivery “panel” and declared on several occasions that delivering water rights in accordance with water availability and water demand was important and that RUBDA should assist decision makers in doing that. But the analysis of the objectives and options selected by the informants revealed that the informants did not define delivering realistic Water Rights or reviewing Water Rights to reflect the available water in the rivers as an important objective nor as an appropriate way of managing water resources in the basin. Water Rights were not perceived to be a management instrument.

An interesting observation made during the questionnaire survey concerned the gap that existed between the tasks undertaken by decision makers, and what the researchers believed these tasks to be. None of the informants actually declared that defining water allocation strategies was an activity or even an objective. The researchers promoted the use of RUBDA for assisting decision makers in allocating water resources. To do so, researchers (as well as the developer) believed that water allocation could be done using Water Rights, although the decision makers did not prioritise Water Rights as a way of managing water resources. The informants revealed that their main activity consisted of responding to the ever increasing demand for more water abstractions, defining regulations, and then trying to get them implemented. The decision makers did not mention any wider strategy or plan concerning the development of the basin. They were instead involved in what can be called “fire fighting” (as stated by the RBWO officer), which is of course not based on strategies and plans. This observation is also confirmed by the fact that the decision makers did not mention problems concerning missing data or information. Although a few hydrological and water use data were described as missing, most informants declared that they were not using such data to take decisions (although the same data were described as needed for the proper management of water resources). This contrasts with some of the comments made during the workshops where on several occasions some decision makers said that they had insufficient data to take “good” decisions, and that RUBDA would assist them in doing that.

Another important phenomenon observed was that all the proposed indicators, scenarios, and components were validated and accepted with only minor changes.

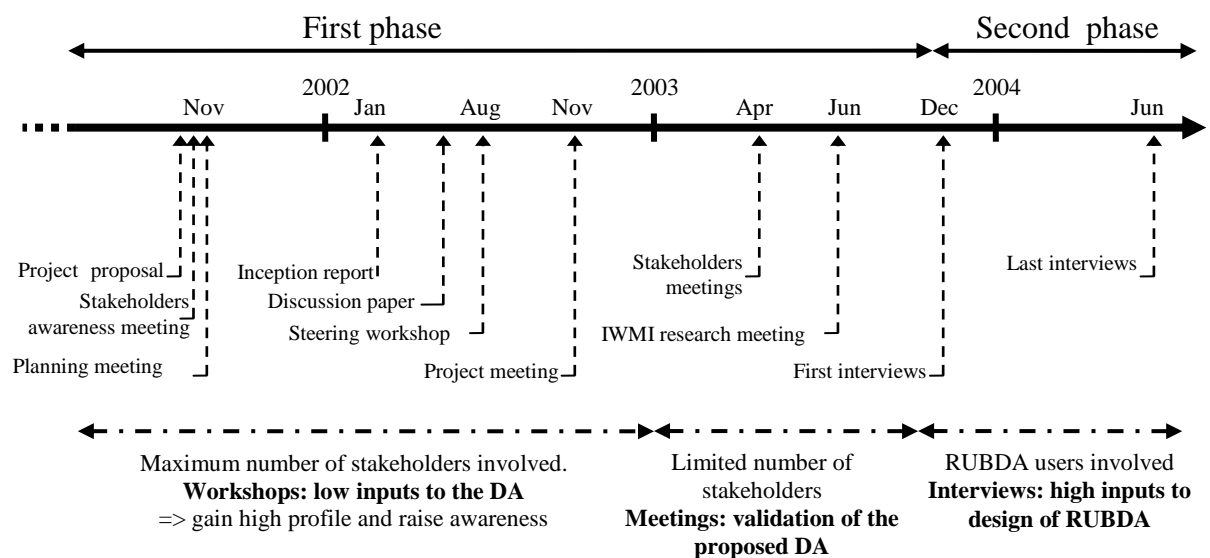


Though some new indicators and scenarios were added, all informants declared that the proposed RUBDA would fulfil their needs. A question arises then, of how RUBDA can fulfil decisions makers' needs when these decision-makers do not seem to depend on data and results to take decisions? This question can partly be answered by considering the fact that the informants always perceived RUBDA to be a tool providing general information about the UGRRC. RUBDA would assist them by providing a better understanding of the system and by assessing the impacts of scenarios but not as a direct aid for day-to-day decisions.

#### 4.7. Discussion

This chapter summarised the progress made on the design of RUBDA while paying special attention to the involvement of users. It covers the first phases of the development of RUBDA from its framing to the end of the questionnaire survey. To simplify the analysis, the period covered in this chapter has been divided into two phases. The first phase started in early 2001 with the project proposal and ended in December 2003. The second phase started in December 2003 and ended in June 2004. For clarity, the two phases were added to the diagram presenting the main events (Figure 11) to generate Figure 17.

*Figure 17: Chronological diagram presenting the various events and phases of the participation process between November 2002 and June 2004.*



During the first phase, the RUBDA initiative was presented during workshops and meetings to a fairly high number of Tanzanian stakeholders. The aim of these events was to get the Tanzanian stakeholders to know the RUBDA initiative and get them familiar with the specifics of the DA. But the project partners and the developer were convinced that in order to fully understand the requirements of end-users of RUBDA and get them to input on the design, some interviews had to be conducted. These interviews had to be held with a limited number of key stakeholders, those being identified specifically as end-users of RUBDA. Thus, the second phase of the participation process based on one-to-one semi-structured interviews (conducted using questionnaires) started in December 2003.

#### **4.7.1. Critical evaluation of participation methods and of their contribution to the development of the DA**

While the presentation to stakeholders was useful as a first step towards participation, it did not generate sufficient inputs from the participants. During the framing and the inception phase, the participation of stakeholders was organised through workshops which enabled participants to understand what DAs and their aims are. A large number of stakeholders (more than 50) were aware of RIPARWIN and of its initiative to develop a DA for the management of water resources in the UGRRC. During these workshops, the aim was to target the maximum number of Tanzanian stakeholders though not necessarily from the study area. The workshops were packed with large numbers of participants, however few made comments. The main contribution from these workshops was that they provided a rationale to RIPARWIN.

The next step of the participation process was conducted using meetings with specific stakeholders from the UGRRC. These meetings targeted a more limited number of stakeholders (about 25) from various organisations working in the studied area. Thanks to these meetings they became aware of the specifications of RUBDA, its aim, its proposed structure and different components. Some interesting discussions were held during the meetings and most of the comments were positive about RUBDA. The participants were enthusiastic about getting a tool that would assist their management of water resources in the very complex UGRRC. Very few contributions were obtained

from the participants during these meetings but the proposed RUBDA was validated as appropriate. By contrast, the meetings held between the project partners were very prolific, and the researchers keen to contribute to the design of RUBDA. Thus, most of the contributions (not to say all of them) originated from literature review, researchers and developers.

The developers and project partners remained convinced that they wanted to develop a user-oriented DA. It was therefore decided that the next step in the participation process would be to conduct one-to-one interviews with stakeholders from the different institutions and management bodies identified as potential users of RUBDA. The interviews were conducted using a questionnaire survey. This survey constituted the second phase of the design of RUBDA. These interviews allowed the developers to better understand users' expectations and to get real interactions and inputs that were meant to shape the design of RUBDA even though most of the decisions regarding the design of the DA had already been taken. Although there were some significant contributions gathered during the interviews, there were no significant changes made concerning the structure and components of RUBDA. In fact, almost all of the proposed indicators, scenarios and other components of RUBDA were validated by the informants. All the targeted users declared that the proposed RUBDA would fulfil their needs.

#### **4.7.2. Rationale and purpose of RUBDA**

Whilst RUBDA was called a decision aid, the decisions that needed to be aided were never clearly identified. The only statements about this issue related to decisions linked to the allocation of water, but it remained unclear what kind of decisions this entailed. This vagueness was partly due to the ever increasing number of users that were identified to be "aided" by RUBDA. The result of not knowing precisely what decisions should be supported (or more precisely, trying to assist all the decisions that need to be taken by the very large number of potential users of RUBDA) is that the definition of the aims of RUBDA were rather general in nature. This phenomenon was emphasised by two objectives of RIPARWIN, i.e. to develop a tool to:

- Raise the understanding of the GRRC system in general (and not necessarily aiding decisions);
- Assist decisions regarding water allocation that comply with IWRM – an ambitious objective, difficult to quantify.

The reaction of the project partners was to think that RUBDA would assist users in defining water allocation strategies, yet none of the informants actually mentioned this as an activity. The decision makers were not defining water allocation strategies or plans because of their involvement on a daily basis with decisions regarding the ever increasing demand for more water abstractions, defining restrictions and then trying to get them applied by water users. A gap therefore existed between how water rights were perceived by the researchers (as means to manage water uses and to allocate water resources), and how they were perceived by the decision makers (as formalising and registering water uses). The survey showed that water rights were not perceived as a management instrument and therefore RUBDA would not assist their implementation. The informants perceived RUBDA primarily as a tool to provide general information about the UGRRC which would assist them by providing a better understanding of the system and by assessing the impacts of scenarios.

### **4.7.3. Unpicking the participation process**

The participation process offered the users several occasions to contribute to the design of RUBDA but they did not contribute much apart from validating the DA they were being proposed. One way of measuring the success of the participation process is to analyse the extent to which the requests and contributions of the users were collected and taken into account by the developers. The users had several occasions to raise their concerns and to influence the design of RUBDA; workshops, meetings and one-to-one interviews. From the RIPARWIN project's perspective, the participation of stakeholders was a success. All the components of RUBDA were presented and validated by the stakeholders. However, their true level of involvement and influence on the process can be questioned. Two issues must be understood in order to explain why RUBDA was designed by researchers themselves.

First, the developers considered that the targeted users of RUBDA were also trying to implement IWRM, then it is understandable why developing a tool to perform IWRM would necessarily answer users' needs. As presented here, this assumption seems rather naïve. But it was legitimised by two “phenomena”. The first was that IWRM was seen to be the proper way of managing resources when the project was started. The second “phenomenon” was that the decision makers actually declared on several occasions that they were trying to implement IWRM as it was planned and stated in policies (see Chapter 3). The way Tanzanian stakeholders expressed themselves and contributed during workshops and meetings contributed to entertain the belief they were trying to implement IWRM. These created conditions favourable to a DA designed by researchers and validated by users instead of a DA being designed by users.

The way potential users of RUBDA responded to the various opportunities they were given to have an impact on the design of RUBDA showed that although they were enthusiastic about getting a DA they were not necessarily keen to participate actively to its design. During the first phase, from 2001 to December 2003, participants attending the different workshops and meetings did not challenge or even comment upon the proposed DA. During the second phase (the questionnaire survey), users contributed much more but were not keen to challenge what was proposed by the developers. Instead they were very enthusiastic about getting RUBDA. As a result, the output of the participation process described in this chapter was that RUBDA was designed as a research tool designed by researchers and validated by Tanzanian stakeholders. The second issue is more anecdotal but quite revealing about the importance given by the decision makers to their involvement in the design of RUBDA. The developers had difficulties to get the same participants involved regularly during the design phase. For instance, the members of the Mbarali District Council that attended the various meetings had to vary from one workshop to another in an effort made by the director of the Mbarali Council to share equally the per diem given during some of the workshops. Thus, the director of the Mbarali District Council requested that the invitation letters be sent to him directly and that he would then choose the representatives to be sent to the workshop. The choices were made regardless of the representatives' interest for the development and use of RUBDA.

During the participation process users were involved and given a chance to contribute, yet RUBDA would not directly assist their decisions. Instead it will help them to better understand the UGRRC and in particular to understand the impact of the various water allocation strategies that could be implemented.

#### **4.8. Conclusions**

This chapter reviewed the development of the DA from the framing of the development initiative to the end of the design of the conceptual DA (2001 to June 2004). The design was mainly shaped by the contributions of the RIPARWIN project partners. The main output of the design phase was a research Decision Aid called RUBDA aimed at assisting Tanzanian decision makers to allocate water resources in an integrated manner.

In general the users were satisfied by the conceptual DA proposed by the developers, for its aim, structure and components were validated during the participation process. The participation of the users was conducted using workshops, meetings and interviews and involved a large variety and number of stakeholders from Tanzania (during the workshops) and from the UGRRC (during the meetings and interviews). The participation process was more a success in terms of number of events than in terms of users' contribution. The developers had some difficulties to understand and capture the needs of the potential users and especially the decisions (and their processes) that needed to be assisted. An ambiguity which remained throughout the design phase concerned the users targeted by RUBDA. At the launch of the development initiative and during the first steps of the design, the DA was meant to be used by researchers and all the stakeholders of the UGRRC, including water users such as farmers. Yet the DA was computer-based and in English (two very restrictive conditions for Swahili speaking farmers) and farmers were never consulted.

Although some efforts were made during the questionnaire survey to narrow down the targeted users, the aim of developing a tool generic in nature and flexible enough to meet all users' needs remained. This was mainly due to the desire by the project research partners to develop a tool in line with the IWRM principle claiming that all

stakeholders must be involved in the management of water resources. Thus, instead of being a tool to assist targeted users' specific decision mechanisms, RUBDA was perceived to be a tool to enhance general knowledge about the management of water resources in the UGRRC. The differences that exists between the discourse of water resources managers (demanding for a DA, keen to participate to the project) and their real needs (they do not use data) is symptomatic of their position in the African society. On the one hand, they are representatives of the formal/legal and regulatory framework of water management that prevails at the national and international level and on the other hand they are almost powerless in front of the set of local, community based practices that are normally determined by local customs, traditions and culture of the water users.

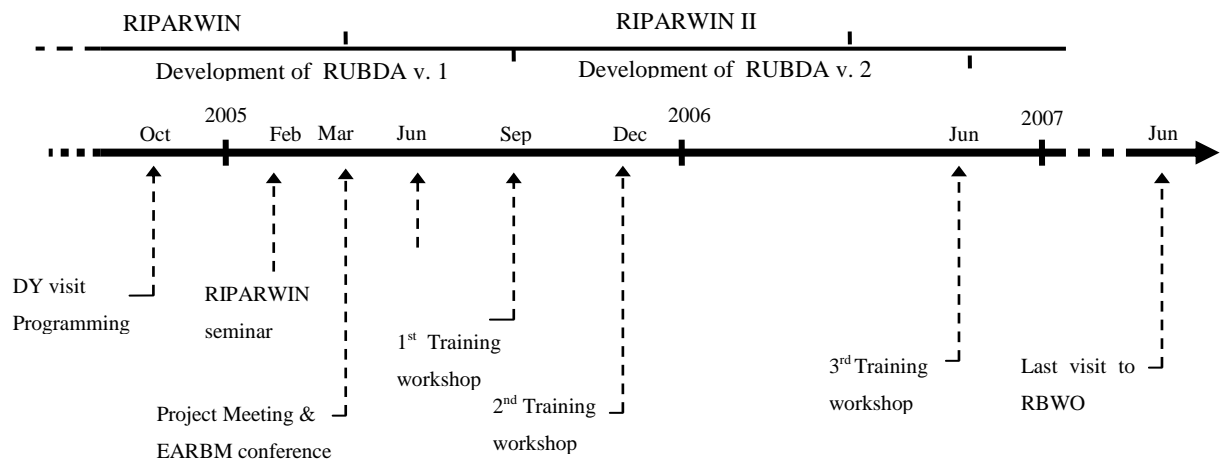
Towards the end of 2004, the programming work on RUBDA intensified and a draft version of RUBDA was developed shaped by the outputs of the design phase described in this chapter. The review of the participation process and especially the extent to which the users and the project partners contributed to the design of RUBDA will be used to shed light on the origins of the flaws of the DA developed and on the reasons that led the developers to change the development methods. The next chapter describes in detail the development of RUBDA version 1 and explains why and how a second version of RUBDA was eventually developed.

## Chapter 5 - Development of RUBDAv1 and RUBDA v2 from process-oriented to a user-oriented tool

### 5.1. Introduction

This chapter presents the development of the two versions of RUBDA between 2005 and 2007 (Figure 18). It analyses (1) the development methods used, (2) the choices made by the developers in response to local and project constraints and (3) the outputs of the three RUBDA trainings. The first training showed that RUBDAv1 did not meet users' requirements and, as a result, developers decided to change their development approach to produce a second version. Although RUBDAv2 did not get rid of all the weaknesses of RUBDAv1, the use of development methods derived from software engineering sciences led to significant improvements. The lessons learnt and the experience gained from this exercise brought to light numerous flaws in the development process.

*Figure 18 : Time chart of the development of RUBDA and main events from 2004 to 2007*



### 5.2. From the design to the development of RUBDAv1

This section describes some of the choices that had to be made by the developers concerning the functionalities offered by RUBDA. These choices were ambitious because they resulted from the many requests made by project partners and other



potential users during the participatory process (see Chapter 4). Other development choices had to be made because of local constraints such as the unwillingness of some institutions to share their data. By the end of 2004, a draft RUBDA had been designed as a research tool aiming at assisting the UGRRC decision makers to allocate water resources in an integrated manner.

RUBDA's structure, components and objectives were defined in an iterative manner and evolved between 2001 and 2004 as described in Chapter 4. Although some work had been done before 2004, most programming was achieved during 2004. When the programming phase started, RUBDA was defined as a tool that aimed (1) to act as a database and offer GIS facilities, (2) provide knowledge of the allocable amount of water available for each sub basin and (3) allow users to run scenarios by modifying inputs parameters such as climatic conditions, water abstractions (in particular the irrigation abstractions), environmental requirements of the wetlands and the RNP and demographic changes in the UGRRC. The list of RUBDA's expected outputs was as follows:

1. For a particular year, provide the amount of water reaching the RNP, the Mtera Kidatu system, the Ihefu wetland and available for irrigation
2. Area under different land uses
3. Sectoral water use per basin
4. For a particular year, provide river flows in key points:
  - One upstream Mtera at Msembe ferry
  - Entering RNP
  - Upstream Ihefu
  - Mbarali downstream and upstream of irrigation scheme
  - On Ruaha, Kimani, Ndembera and little Ruaha rivers
  - Irrigation requirements
    - On the large irrigation schemes, except for Mkoji
    - On chimala River at Chitekelo
    - On Mswiswi, Mambi and Lunua rivers
5. Economic and (some) social indicators for each sector at the sub basin-level.

This list of expected outputs was discussed during a RIPARWIN meeting between the developer and the project leader. It appeared shorter than initially described at the end of the participation process because it was found necessary to scale down the initial, ambitious specifications and functionalities of RUBDA and improve its outputs. The aim was not to permanently remove functionalities but rather add them progressively. Thus, the programming work plan that was agreed upon at the beginning of 2004 did not entail all the functionalities identified during the design phase. The work plan took into consideration the time constraints and the manpower available for the development of the various modules. Although the number and variety of outputs had been revised, developing a DA capable of generating improved outputs was still very ambitious and demanded a considerable amount of work. As shown in the next section, the list was further reduced at a later stage because of project as well as local constraints that limited the feasibility of developing some components. Being faced with a number of constraints, the developer and the project leader had to make choices to ensure that a working version of RUBDA was developed.

### **5.2.1. Constraints on development choices**

The constraints that have had an impact on the development of RUBDA and on its functionalities and outputs are numerous and of different nature. They are linked to the nature of the project itself and the way it was conducted but also to the Tanzanian and UGRRC context. Efforts were made to describe the way both developer and project partners reacted to the constraints, especially choices made and their impact on the nature of RUBDA. The causal effect between constraints and choices was complex. The aim of this section is less to show how development decisions were taken in relation to the constraints than to explain how the project and local context impacted on the development of RUBDA and consequently modified earlier decisions. Many new decisions had not been anticipated, ranking from minor ones such as the way users names were handled or the number of buttons on each interface, to major issues linked to RUBDA's functionalities.

To illustrate those changes, four different cases of decisions taken by the developers are described here. They were chosen because of their representativeness of different

constraints. Decisions 1 and 2 illustrate the impact of local constraints whereas decisions 3 and 4 show the influence of constraints linked to the project itself:

1. Programming languages used
2. Management of data and databases
3. Development of a GIS
4. Development of the Outcomes Impact Model.

### ***Programming languages used***

The programming language used was a critical choice. It became clear that that choice generated programming complexities which lead to time spent on basic programming rather than on making a user-friendly piece of software.

Hydrological modelling was programmed in FORTRAN 90 while other components, including interfaces, were programmed using VISUAL BASIC 6.0. These two languages were chosen because there were the two main languages learnt and used at Sokoine University of Agriculture, an important RIPARWIN partner. FORTRAN was also chosen because it is appropriate for scientific modelling and because the former hydrological model, the Usangu Basin Model (UBM), which is the core of RUBDA, was developed in FORTRAN 77. Hydrological components were thus programmed in FORTRAN 90 or recompiled from FORTRAN 77. Demand management tools and interfaces were programmed in VISUAL BASIC 6.0 because it was familiar to project members and provided ready made codes that eased the development of windows-like interfaces.

FORTRAN and VISUAL BASIC appeared at the beginning of the project as the logical choice to make in order to get as much assistance as possible from Tanzanian project partners. This choice was also motivated by the belief that it would facilitate the take over, the maintenance and the future upgrades of RUBDA by the Tanzanian partners once RIPARWIN would end. This argument was at that time very important for the RIPARWIN leader because the aim was to develop a water management tool that would be the basis for further improvement and that would rely on the long term partnership between the SUA and the UGRRC institutions. The aim here was to reduce the chances of developing a tool in a language that would not be usable by the Tanzanians and

increase the chances of seeing RUBDA's development and improvement continue after the project lifetime. Unfortunately, these two rather old fashioned programming languages appeared as a constraint and a limiting factor because of their limited capacities compared to more recent programming languages. At one point of the project, it was even envisaged to opt for JAVA and some tests were realised. This solution was nevertheless abandoned because it would have been extremely time consuming. The reprogramming of FORTRAN-written modules into VISUAL BASIC for compatibility with Windows' recent versions was also not possible without major delays.

### ***Management of data***

Another modification of RUBDA's functionalities that appeared necessary was about databases. During the design phase, it was decided that RUBDA needed to centralise a large amount of data that were scattered between the various institutions involved in the management of water in the UGRRC and at National level. The plan was also to centralise data gathered from the various projects, including the RIPARWIN project and the local institutions into two databases, a tabular database and a GIS database. Consulted participants felt that this component of RUBDA would be very useful and were enthusiastic about getting access to a large quantity of data. However, when development started, most institutions (such as the Ministry of Water and Livestock Development of the Ministry of Environment) refused to provide their data and allow their storage in RUBDA. Their decision was explained because of the economic value of data, which are sold to users. Although this did not seem to represent significant income for the different institutions, the sharing of data appeared not feasible.

### ***Development of a GIS***

From the first step of the launch of the DA initiative under RIPARWIN, it had been decided that the DA would have to "operate on a GIS-ARC View environment" in order to allow integrated analysis, provide a "basin-wide" representation of WRM and make the work/result transparent to users (Rajabu, 2002). The GIS was perceived as required for IWRM. During the design phase, the GIS component of RUBDA was included as one of the functionality offered in all project documents and was presented and

validated by participants at numerous meetings and workshops. Toward the end of 2003 a shift occurred concerning the role of the GIS environment because the hydrological model was being given a central role. In project documents written in 2004 and 2005, RUBDA is not any more described as being built around and operating on a GIS environment but rather offering GIS “facilities” providing spatial and technical information related to mapped objects. At this stage, the aim had simply become to link the tabular database containing the input and output data to a spatial database so that information would be displayed using a GIS viewer.

At the end of June 2003, the developer visited the representatives of ESRI in South Africa (GIMS offices in Pretoria) and identified the MapObject Lt software as appropriate to develop the RUBDA GIS. MapObject Lt entailed a number of modules that were used to develop ArcView and Arc Explorer software that are used by a large number of organisations (including IWMI, SUA and the RBWO) to perform GIS activities. Each module corresponds to one or several functionalities and can be combined according to the needs of developers to build a GIS viewer. This technology was also convenient because in its “light” version, only one license had to be purchased and could be distributed freely to 50 users. IWMI agreed to purchase the licence.

In 2004, RIPARWIN started the development of the GIS for RUBDA. The necessary work did not exceed two or three weeks but required some specific skills. It appeared rapidly that the RIPARWIN developer lacked the required skills and a consultant was hired among the GIS unit of the Sokoine University of Agriculture. Specific terms of references were developed but the consultant did not manage to develop the GIS viewer. Because hiring an international consultant was too expensive and had not been budgeted for, it was decided that the GIS viewer would not be developed. Instead, ArcExplorer 2.0 was chosen. ArcExplorer 2.0 is a light, freeware version of ArcView developed with the MapObject technology. Choosing ArcExplorer 2.0 implied that the GIS viewer would have very limited functionalities (open layers and projects, create and print maps) and it was therefore not possible anymore to link it to the input/output database used by the hydrological models.

Beyond the extra cost of hiring an international consultant, this choice was also motivated by other causes. Firstly, the RBWO already had a GIS unit in its main office

and, although the GIS component had been validated at many occasions during the design phase it did not appear as a priority during the interviews to make use of this unit. Secondly, the fact that it had not been possible to develop the tabular database (because most data could not be provided freely to users) made less necessary the development of a dynamic spatial database (that would have been linked to the tabular database).

### ***Development of the Outcomes Impact Model***

The Outcomes Impact Model (OIM) was, with the GIS, one of the functionalities identified as a priority during the design phase (see Chapter 4). It was perceived by project partners as one of the tools that would enable the implementation of IWRM. Allocating water resource using a social and monetary evaluation of water productivity per sector is one of the requirements of IWRM (see section 4.4.4). The OIM was intended to transform the sectoral water uses results into social and economic water productivity (jobs/m<sup>3</sup> or \$/m<sup>3</sup>) in order to provide decision makers with an estimate of the costs and benefits of each water use for the whole basin. The idea was to generalise the economic water productivity indicators estimated for the Mkoji Sub-catchment<sup>15</sup> to the whole of the UGRRC.

The OIM was actually never achieved nor included in any version of RUBDA. The main reason for this is that the so called social indicators that had been identified during the design by IWMI researchers were very difficult to estimate. Project partners (including developers) were reluctant to provide monetary valuations without social values of sectoral uses because the use of this data could have been misused or misinterpreted by end-users. Developers were keen to include OIM but it was finally abandoned (see later in this chapter) because users did not perceive economic indicators as factors influencing the allocation of water in the UGRRC.

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<sup>15</sup> From August to November 2003, the RIPARWIN project research associates were hired to conduct a study for the FAO funded by the Netherlands. This field work based study aimed to estimate the water productivity, in monetary terms, of the different water uses in the Mkoji Sub-Catchment, one of the sub catchments of the UGRRC.

### **5.3. RUBDAv1: A model-centred tool**

The first working prototype of RUBDAv1, used during the first training event, was focused on the Graphical User Interface (GUI) and built to ease “dialogue” between users and the various programs. However, the functionalities defined by the researchers in order to develop an integrated tool for IWRM had to be supported. As a result, RUBDA in its very first version was a strict research tool where modelling (hydrological and economic) is given a central role. RUBDAv1 was a modelled centred tool in which the GUI was not designed according to the users’ needs but instead according to modelling requirements.

#### **5.3.1. Structure and Graphical User Interface**

This section described the GUI that was developed for RUBDAv1, it shows that its complexity can be linked to its design. RUBDAV1 is divided into three independent components: Water Management Modules, GIS viewer and Hydrological and Outcome Model (Figure 19). Each of the three components has its own interface but is accessed through a common, main window (Figure 20).

The main window’s tool bar has buttons to access basic functionalities: Logout, Menu, Exit, Introduction, and Help<sup>16</sup>. The Menu window gives access to the GIS Viewer, the Hydrological Model and the Water Management Modules. The Hydrological Model is the set of interfaces that allow loading, creating, and running a scenario. Scenarios are created by modifying the input data of the various hydrological sub-programs. The interfaces allow users to modify or validate the default input data.

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<sup>16</sup> The login/logout, introduction and help functionalities (that are also accessed through the tool bar) remained almost the same in the second version of RUBDA and are described in detail in Chapter 6Partie I. Chapter 6 - .

Figure 19 : Schematic diagram of the various RUBDAv1 windows

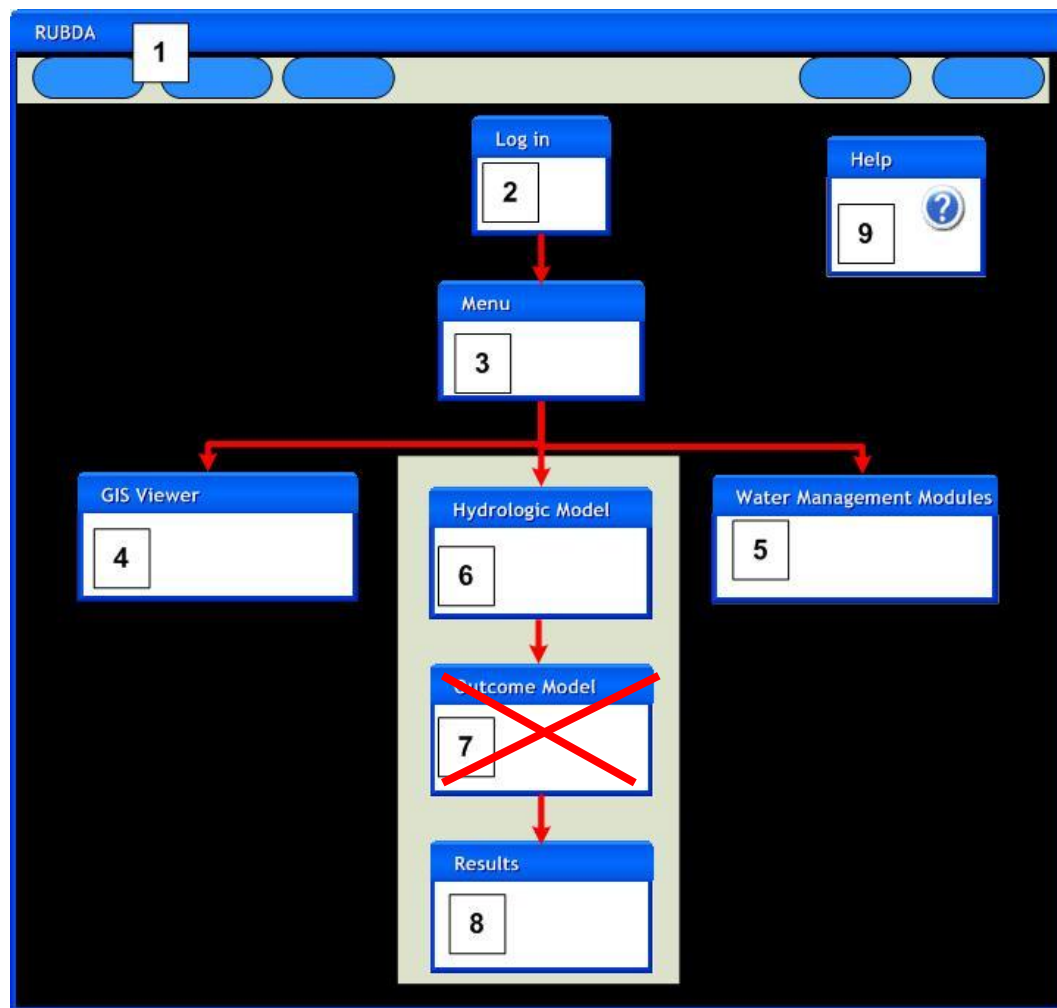
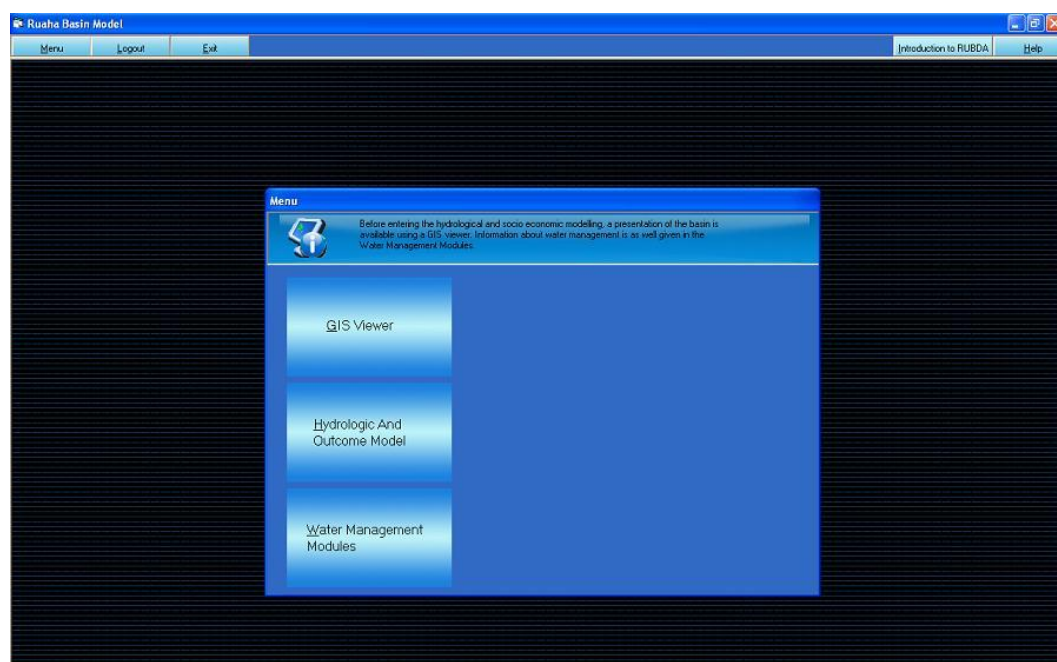


Figure 20 : Screen shot of the “Menu” window in RUBDA v1





During the design phase, hydrological modelling was described as the core of RUBDA. As a result, most efforts concentrated on developing an interface that would allow users to “dialogue” with the hydrological programs. Hydrological modelling comprised nine different sub-models (programs extracted from the UBM – see Chapter 7), that needed to be run in a certain order, from upstream to downstream of the catchment. Since hydrological modelling was at that time given the highest importance, it made sense for developers to develop one separate interface for each sub-model. Thus, the Hydrological Model required users to go through 10 different windows, following the hydrological modelling of the catchment. In some of the interfaces, the users were requested to go through 2 or 3 tabs which added to the users’ confusion and increased the unfriendliness of the GUI. The interfaces were built as a linear sequence in which each step depends of results generated during the previous steps. In contrast, the GIS Viewer and the Water Management Modules only required one or two windows to be accessed.

Each UGRRC hydrological unit of the UGRRC was modelled by a hydrological sub-program. These sub-programs modelled the rainfall and runoff, river flows and routing downstream to the wetlands and through the RNP. Some of the inputs can be modified by users and the outputs generated are used as inputs by one or several sub-programs modelling the downstream hydrological unit. Since these programs use text files as input and outputs files, modifications made by users had therefore to be saved before running the programs. Users’ choice can be made (se Figure 5) by selecting among proposed data (e.g. rainfall) or by entering own data (e.g. water demand, threshold runoff for the floodplain). The default scenario can be reloaded if the user is not satisfied with modifications. Once the input data are selected, the user has to move to the next window. The program then runs before opening the next window. Although this type of programming was fixed and linear, it was chosen by the developers because they believed it was the simplest way for the user to interact with the hydrological models.

Figure 21 presents the First Demand Interface, as an example. On this window, the user can enter or modify water demand (average monthly or annual abstraction, in  $\text{m}^{-3} \text{s}^{-1}$ ) per sector, sub-catchment and location. Clicking on the sub-catchment’s name opens a map showing the UGRRC and the location of the various sub-catchments. Figure 21 is a

clear example of the complexity and unfriendliness of the interfaces that were developed in RUBDAv1.

Figure 21: Hydrological model.Demand Interface

Annual average		Monthly average												
		J	F	M	A	M	J	J	A	S	O	N	D	
Itambo	0	0.268	0.290	0.285	3.730	5.338	4.690	3.490	5.281	3.454	0.891	0.249	0.258	<input checked="" type="checkbox"/>
Chimala	0	0.400	0.400	0.400	2.425	2.597	2.094	1.714	2.447	1.278	0.428	0.400	0.400	<input checked="" type="checkbox"/>
Great Ruaha	0	0.200	0.200	0.200	4.735	4.485	3.395	2.934	3.993	1.634	0.239	0.200	0.200	<input checked="" type="checkbox"/>
Kimani	0	0.200	0.200	0.200	3.483	3.778	2.778	2.403	3.373	1.632	0.292	0.200	0.200	<input checked="" type="checkbox"/>
Mlomboji	0	0.000	0.000	0.000	0.036	0.012	0.014	0.012	0.012	0.000	0.000	0.000	0.000	<input checked="" type="checkbox"/>
Mbarali	0	0.400	0.400	0.400	8.049	7.548	5.714	4.943	6.780	2.785	0.448	0.400	0.400	<input checked="" type="checkbox"/>
Kioga	0	0.063	0.069	0.067	6.018	6.283	4.492	3.975	5.604	2.553	0.215	0.059	0.061	<input checked="" type="checkbox"/>
Ndembera	0	0.250	0.250	0.250	3.995	4.695	3.558	3.394	3.747	1.548	0.031	0.000	0.167	<input checked="" type="checkbox"/>
North Eastern	0	0.000	0.000	0.000	0.002	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	<input checked="" type="checkbox"/>
Kimbi	0	0.000	0.000	0.000	0.052	0.017	0.020	0.018	0.017	0.000	0.000	0.000	0.000	<input checked="" type="checkbox"/>
North West	0	0.268	0.290	0.285	4.104	5.537	4.861	3.645	5.460	3.454	0.891	0.249	0.258	<input checked="" type="checkbox"/>

### 5.3.2. Results component

Scenario results are presented in three different formats and three different windows: “Graphs”, “Data summary” and “Indicators”. The Graphs window (Figure 22) gives river flows before and after each hydrological component. For each location, users can view inflows, outflows, water demands and water uses. Curves for different sub-catchments, inflows and outflows can be superimposed for comparisons. Rainfall data can be displayed. River flows values are generated from the text files of the various sub-programs using the scenario input data. When selecting a sub-catchment, the curves and indicators are generated using daily river flows and water demand, taking into account the water demand priority setting chosen. Zooming is possible, as well as clicking on any point of a curve and getting the corresponding value.

Figure 22 : Main graph window

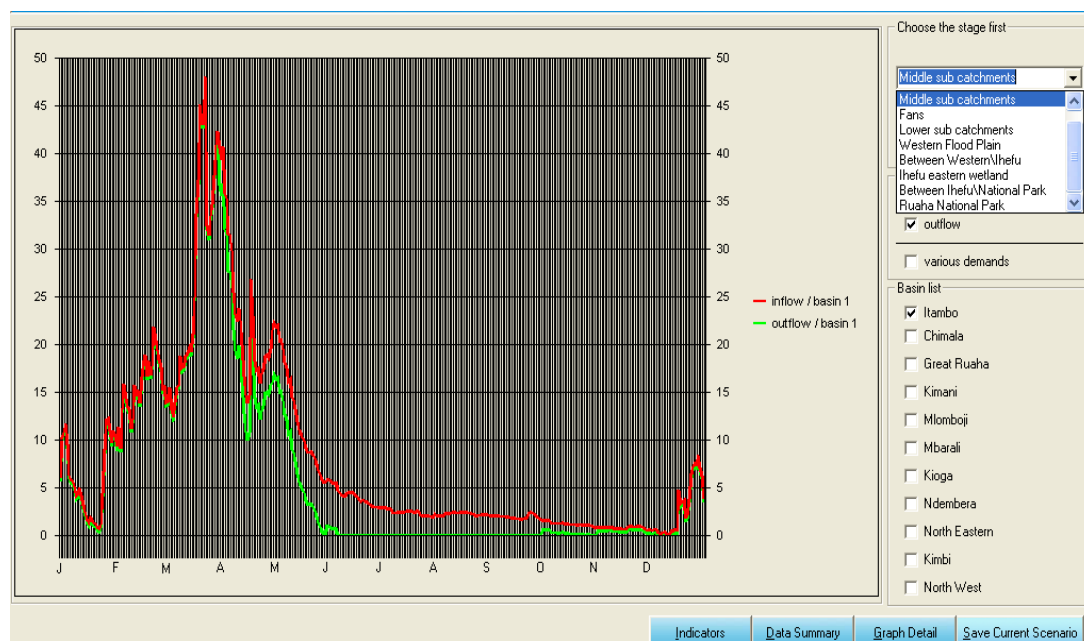
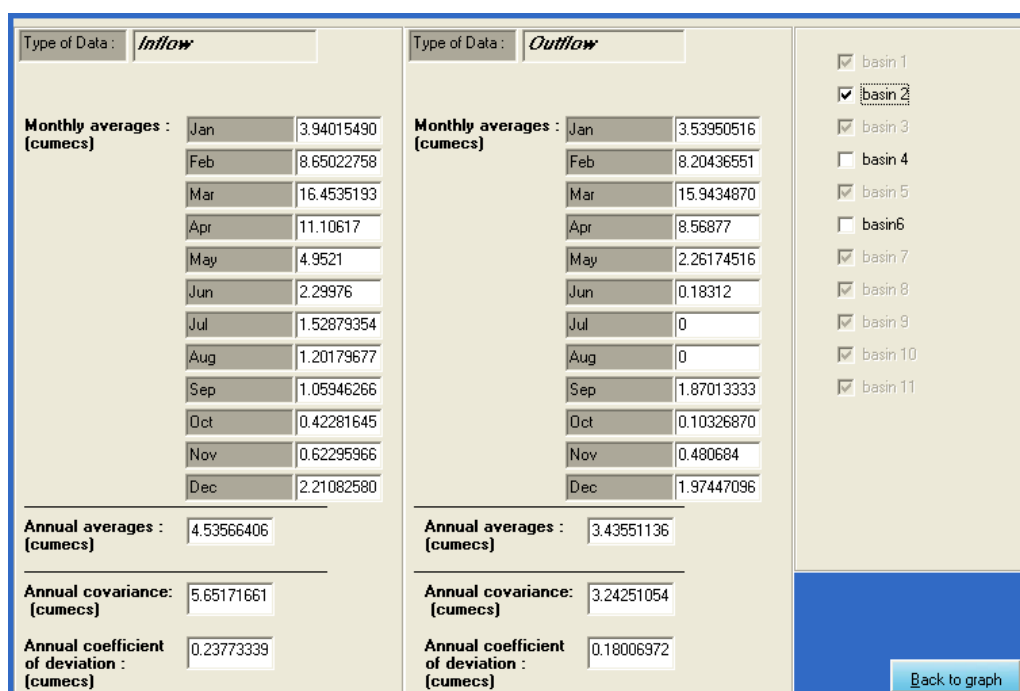
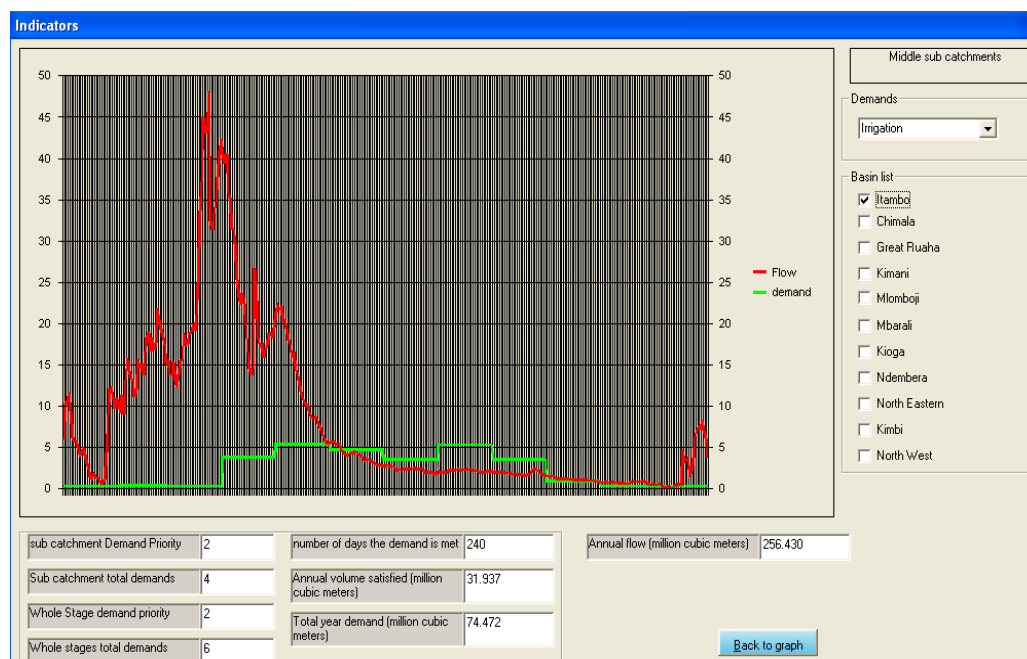


Figure 23: Data summary



The Data summary window (Figure 23) shows the estimated monthly and annual averages as well as the annual covariance and coefficient of deviation for the curves displayed on the graph window.

Figure 24 : Indicators



The Indicators window (Figure 24) is intended to facilitate decision making. Indicators come from processed data that are not purely hydrological (Graphs) or mathematical (Data summary). Various indicators are displayed such as the number of days the water demand is met during wet and dry season and the supplied volumes.

#### 5.4. RUBDAv1 first training

In September 2005, a two-day training workshop was held at the regional office of the Rufiji Basin Water Office in Iringa, organised for potential users of RUBDAv1 (Figure 25). There were 15 participants invited that belonged to the RBWO, the Ministry of Agriculture and the Ministry of Environment. Presentations of RUBDA took place on the first day, followed by computer-based simple exercises in groups of 2 or 3 people. Full-size exercises using all RUBDA features were implemented during day 2.

The outcome of the training was a sort of "role playing game", since participants tested RUBDA in a "real situation". The participants were separated in three groups and each group endorsed the role of three different actors: Irrigators, the Ministry of Environment, and the RBWO. Each group had to use the software to create the scenario corresponding to the role of the group in question. Scenarios and results were vividly

discussed between groups. Discussions between participants were perceived by project partners as very promising. The hydrological modelling combined with the indicators proposed by RUBDAv1 could be used by the various actors linked to the management of water in the UGRRC to test various water resources allocation strategies.

*Figure 25 : Participants doing the exercises on RUBDAv1*



Five “trainers” (including the two developers) observed and recorded difficulties encountered by participants on e.g. navigation between components and windows or the understanding of information given and inputs required. Participants’ feedback was captured in different ways: a) the trainers observed how RUBDA was used and where participants encountered problems, b) participants were asked at the end of each exercise to give the trainers feedback on the problems encountered and the improvements required and c) through the evaluation forms that participants filled at the end of the training.

#### **5.4.1. Comments and observations captured during the training**

##### ***Usability***

1. Navigation was a problem; users didn’t know where they were and often asked to go backwards. There were too many windows in the Hydrological Model.
2. Participants wanted to get intermediate results downstream of the various sub-catchments.
3. Results’ interfaces too complex. The concept of having a main window and a child window (showing with more details a selection of the main window) was not understood by users.

4. Users do not read the help given at the top of the windows. Contextual help appeared as more adapted.
5. The Reload function (to reload default data) was never used.
6. Users forgot the login name they had entered, created different ones and therefore lost the scenarios that they had run.
7. Need to show the structure of the DA at the beginning to ease the navigation.

### ***Utility***

1. Users had different ways of entering/modifying data but most of them only changed the irrigation demand for a particular month or sub catchment and did not try to give a general increase or decrease corresponding to a particular strategy.
2. Asking users to enter or modify the start outflow for the eastern wetland model was useless and a source of confusion.
3. Some components were not used, e.g.: GIS Viewer, Fan type window, western flood plan threshold value, demands in the lower part of the Ruaha catchment, first flow in the Eastern wetlands.
4. The GIS tool did not give enough information, it did not attract users.
5. Users would rather compare the results of a particular sub-catchment at various stages but not compare results from different sub-catchments at a given time.

### ***Modelling***

1. Some users proposed that the environmental flows could be entered as water demand instead of flow requirement.
2. Most users did not understand what monthly averages of water abstractions in  $\text{m}^3\text{s}^{-1}$  represented (especially demand abstractions).
3. Relative and absolute priority concept was not well understood.
4. Users wanted the hydrological year to start in November instead of January.
5. Users wanted to be able to set proportional priorities for the demands.
6. Many participants proposed the use of building blocks method to generate sectoral water demands instead of entering directly water abstractions.

### ***Programming***

1. There were some compatibility and portability problems when RUBDA was setup on different computers. There were problems linked to the version of Windows

installed (e.g. Windows 98 or 2000) as well with the character defined by Windows as the thousands delimiter (dot or coma).

2. Some scenario data were lost when users did not save the scenario before exiting the hydrological model.

#### 5.4.2. Analysis of the evaluation forms

At the end of the training, participants were asked to fill anonymous evaluation forms. They were asked to evaluate RUBDA's user-friendliness and modelling, its usefulness as well as the organisation and the quality of the training itself. Table 14 shows the score given by participants (max = 10).

*Table 15 : Evaluation scores after RUBDA training*

	Lowest (score/10)	Highest (score/10)	Average (score/10)
Explanations and help	5	10	7
Navigation	5	8	7
Data management (display reading entry)	5	10	7
Interpretation of results	6	8	7
Modelling of hydrology and demand	5	10	7
Future usefulness	6	10	8
Workshop organisation	7	10	9
Training quality	7	10	9

Participants were also asked to propose ways of improving RUBDA and the training. The main improvements were as follows (figure in bracket is the number of time the improvement was mentioned):

1. More data on the demand modules (e.g. sub-catchment characteristics) and guidelines for entering water demands (\*3)
2. Water Demand per sector should be modelled using building blocks method (\*3).
3. Improve user friendliness; Huge potential for RUBDA but user friendliness is a problem now (\*2).
4. Add more help and explanations within the various windows (\*2) .
5. Include formulas / equations used in the model (e.g. in the help) (\*2).
6. Improve navigation (enable user to go backwards) (\*2).
7. Some labels and units are missing in the results (\*2).
8. Provide intermediate results (\*2).

9. Enable to compare various scenarios at the same time
10. User friendliness of demand module to be improved (especially when entering monthly values)
11. Give examples in the tool itself, sort of tutorials, and reasons for using RUBDA
12. Saving scenarios while progressing between the different interfaces (and not just at the end)
13. Include economic impacts of scenarios
14. Add impact of land use changes
15. Printing option missing
16. Increase relationship with RBWO on advisory roles
17. Enable user to compare rainfall in each sub catchment with available water.

Concerning the training itself, the main improvements asked by the participants were that the training had to last more than two days and the number and variety of exercises had to be increased.

#### **5.4.3. Conclusions of the training**

The first RUBDA prototype was enthusiastically received. Users were willing to participate and to provide feedback on the existing problems and proposed some modifications. The training aimed at both demonstrating RUBDA to future users as well as to obtain an intensive contribution of some potential users to review, complete or modify RUBDA. It was therefore concluded that the training was a success because users were familiarised with RUBDA, and the tool generated interesting discussions among participants regarding water allocation. Developers were particularly satisfied as participants were much more active during the training than during the workshops and meetings organised during the design phase. As stated by Baskerville (1998:99) prototypes are “intended to improve user-designer communication and are successful because they are more effective linguistic artefacts”. The training enabled fully collaborative involvement by the developers and users and significant inputs were gathered that allowed the development of a second version of RUBDA.



From the comments and observations gathered during the training it appeared clearly that:

- There was a gap between users' understanding of the basin's components and the way the hydrology was modelled and displayed
- The display of input data and results were insufficiently intuitive and user friendly
- The linear structure of the GUI appeared not intuitive and rather fastidious. It did not offer the flexibility required to answer users' requirements (such as presenting intermediate results or means of creating scenarios for one particular sub-catchment).

Some problems related to the “man/machine dialogue” through the GUI were observed by developers. They were linked to the use of the hydrological FORTRAN programs' structure and inputs/outputs parameters to generate the graphical user interfaces. In other words, the developers realised that RUBDA had been developed as a model-centred tool instead of a user-centred tool. As a result, users had difficulties to navigate in RUBDA and understand what inputs and outputs data represented both spatially and qualitatively, as well as to create and run « sound » scenarios and extract and interpret results.

Training thus revealed that significant improvements had to be made to RUBDA in order to better meet the needs of users. Since profound changes had to be made, the training appeared to be more a test workshop than a proper training.

Following this first training, developers agreed that it would not be possible to just continue with the development of the missing components in RUBDA, such as the Outcome Model. The whole GUI had to be redesigned, as well as the management of water demand and the result interface. At this point, it was acknowledged that RUBDA had to be transformed into a real user-centred Decision Aid. This decision was critical. It implied that a lot of time would be necessary to restructure and reprogram the GUI and rethink the whole development process. It implied as well that more training would have to be organised in order to test the second version of RUBDA. The functionalities that had not been identified by users as important during the design phase would have to be abandoned.

## **5.5. RUBDAv2: toward a user-oriented tool**

After the first training, it was decided to re-analyse the outputs of the design phase in order to differentiate what had been the requests made directly by users and those identified as important by project partners. On the basis of these outputs, combined with the comments and observations gathered during the training, a new design of RUBDA was achieved. A paper prototype was produced and presented to the RIPARWIN project leader. The new design was validated and the programming of RUBDAv2 started.

The programmer's background in software development sciences provided an extremely valuable input to the development of RUBDAv2. Users' requirements were analysed and a working plan was produced that included specific development and validation phases. The approach adopted was a partial implementation of software engineering and project management methods used by software developers. These methods consider that the development of software has to be conducted as a project and using the project management "sciences" guidelines. Software development borrows heavily from project management, but there are nuances encountered in software development that are not seen in other management disciplines (Morley, 2008).

### **5.5.1. Applying project management to RUBDA: the "theory"**

This section presents the development plan of RUBDA using software project management approaches. The development plan presented is therefore a "what should have been done" scenario. As part of a post RIPARWIN project exercise, the software engineer hired to assist with the development of RUBDA was asked to propose a development plan as it would have been done by his software development company.

#### ***Proposed development plan***

The development plan proposed was completed using the software engineer's experience and existing literature on project management and software engineering sciences. This work will be used as a reference and compared to how RUBDA was actually developed in order to both examine software engineering methods and the

actual development of RUBDAv2 (project management and software engineering methods are described in Chapter 2, sections 2.6 and 2.7).

#### a) **Development cycle proposed**

The RUBDA development cycle should entail the following phases:

- **Analysis (1 week):** developers will analyse the existing documents in order to understand the context of water management in the UGRRC and the objectives and strategies of the actors involved.
- **Specification (1 week):** developers will define the functionalities to include in RUBDA according to the specifications defined by the clients/users in the terms of references.
- **Design (2 weeks):** design the set of functionalities for the proposed solution.

The three phases mentioned above must be detailed in a specification report. Developers would need to comply with the specification report without creating any major changes.

- **Programming (3 weeks):** this is the most important phase of the work, developers will have to code the whole application and conduct regular unitary tests.<sup>2</sup>
- **Unitary tests (3 days):** Once the programming work is complete, the tool will be presented and validated by the project leader. This will enable the validation of the application from a unitary point of view.
- **Integration tests (1 week):** This phase will be particularly difficult because of the large set of computing equipments of the targeted users. A specific methodology will be defined in order to conduct tests on all the computing equipments.
- **Validation test (1 day):** A presentation will be held with the client in order to ensure that the set of functions requested was developed.

Validations are critical when running a project. They are more detailed and precise than project reviews. Validations must be planned and organised and validation mechanisms

must be clearly stated. In order to meet as much as possible the needs of end-users and to ensure the quality of the solution developed, several validations must be organised.

## b) Life cycle

The life cycle proposed follows the « V » model (see section 2.7. ) with three validation phases. This model was chosen because it allows regular and intensive interactions between developers and users. It requires a rigorous validation of each phase by and with the users. The different versions of RUBDA produced during each phase are presented in Table 15.

Table 16: “V” development cycle model applied to the development of RUBDA

Version of RUBDA	Documents	Validation mechanisms	Actors involved
Paper prototype	<ul style="list-style-type: none"> <li>• GUI specification</li> <li>• Function analysis</li> </ul>	<ul style="list-style-type: none"> <li>• Demonstration of the GUI (windows etc.)</li> <li>• Users questionnaire (evaluation and comments)</li> </ul>	<ul style="list-style-type: none"> <li>• Project partners</li> <li>• RBWO</li> </ul>
Prototype	<ul style="list-style-type: none"> <li>• UML modelling</li> <li>• Function analysis</li> <li>• Quality plan</li> </ul>	<ul style="list-style-type: none"> <li>• Presentation of functions</li> <li>• Demonstration of existing functions</li> <li>• Users questionnaire (evaluation of hydrological model, response times etc. and comments)</li> </ul>	<ul style="list-style-type: none"> <li>• Project partners</li> <li>• RBWO</li> </ul>
Draft version	<ul style="list-style-type: none"> <li>• UML modelling</li> <li>• Function analysis</li> <li>• Quality plan</li> </ul>	<ul style="list-style-type: none"> <li>• Presentation of the project</li> <li>• Presentation of the solution</li> <li>• Demonstration of RUBDA using a pre-set scenario</li> <li>• User exercises (initiation)</li> </ul>	<ul style="list-style-type: none"> <li>• Project partners</li> <li>• RBWO</li> </ul>
Release version	<ul style="list-style-type: none"> <li>• Specifications report</li> </ul>	<ul style="list-style-type: none"> <li>• « Real life » scenario exercises</li> <li>• Users questionnaire (evaluation of hydrological model, response times etc. and comments)</li> <li>• Suggestions for next version</li> </ul>	<ul style="list-style-type: none"> <li>• Project partners</li> <li>• RBWO</li> <li>• Donors</li> </ul>

## c) Project means

Developing a new version of RUBDA with clear and precise terms of references would require two analysts/programmers with computers. The programming language chosen would be DevC++ because it is a license free, powerful language.

### **5.5.2. Applying project management to RUBDA in practice**

The design, development, testing and release of RUBDAv2 were achieved in four different phases. Each phase aimed at producing an output - the four versions of RUBDA - and was validated by project partners and users. The four “versions” of RUBDAv2 developed, from the paper prototype to the released version, are presented in this section.

#### ***Paper prototype***

The paper prototype had been done for RUBDAv1 but had to be repeated for v2. The design of the interfaces on paper was done during the days that followed the first RUBDA training. It was achieved on the basis of users’ comments gathered during the training. The developers tried to design an interface that could correspond to the requests made by users. The prototype produced was only validated with project partners because of time constraints.

The paper prototype was a rough, hand sketch of the new interface design. The prototype was presented to project partners (including the project leader), which provided useful feedbacks concerning ways of improving the interface to improve furthermore the usability and the utility of the DA. The paper prototype proposed was modified and validated and the development of the new interface started.

#### ***Prototype***

In December 2005, the second RUBDA training was held in Dar es Salaam, Tanzania. The training lasted two days and was organised the same way as the first training: it started with presentations and was followed by series of exercises. The propotype was a working version of RUBDAv2 but some functionalities were missing. The outputs of the first training, the new interface and the functionalities of RUBDAv2 were presented. Most of the 15 participants that attended the second training had been part of the first training and were therefore satisfied to see that their comments and requests had been

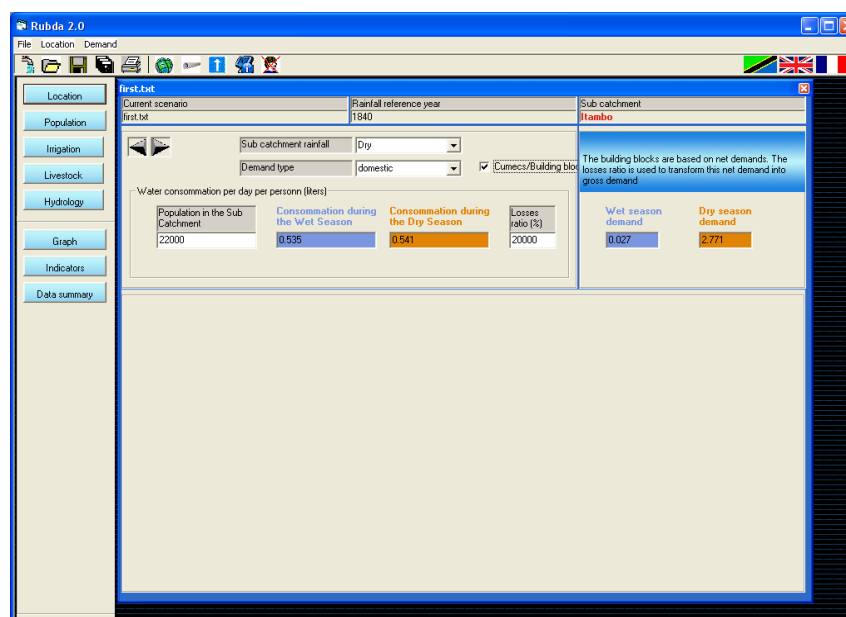
taken into account and RUBDA modified accordingly. The list of comments and proposed improvements was used as a checklist all along the training to check that RUBDAv2 were answering them.

During the training, trainers were asked to observe the way participants were using the DA and note all their observations and users' comments. Some group sessions were also conducted during which participants were asked to reflect on some new functionalities that had to be added to RUBDA. The two main functionalities that were discussed were the model used to build the irrigation building blocks and the priority and water allocation/strategy model.

Participants were, once more, enthusiastic about RUBDA and were active during the different exercises, group sessions and the discussions that followed. Participants were especially satisfied by the new interface (see Figure 24) and the fact that it allowed navigation between the different sub catchments and by the fact that intermediate results were available. There were a great deal of feedbacks was collected. The main comments concerned:

- The bugs that were identified and that limited the use of the prototype. Some were linked to the sub-programs running while others concerned the items displayed on the interfaces.
- The tool bar positioned on the left of the screen that was a source of confusion. Users asked to have all the buttons regrouped in the menus and tool bar located at the top of the screen.
- The priority model and its interface that were judged not satisfactory. Users asked for more flexibility and more options.

Figure 26 : Screen shot of the interface of the RUBDAv2 prototype



### **Draft version**

The 3<sup>rd</sup> training was held in Dar es Salaam on the 1<sup>st</sup> and 2<sup>nd</sup> of June 2006. The training was organised similarly to the first two trainings but more participants were invited as the trainings coincided with the end of RIPARWIN. The draft version of RUBDAv2 was an upgraded version of the prototype. The modified interface and the new functionalities were presented and well handled by users during the exercises.

The original aim was to hand-over the final version of RUBDAv2 at the end of this training. Unfortunately, new bugs were identified during the training (due to the modified interfaces and new functionalities) and it was therefore decided that the final version would be released within a month. The RBWO was as well keen to delay the release as they requested RUBDA to be updated with the 2005/2006 rainfall data.

### **Release version**

The final version was released to the RBWO and the Mbarali District Council in August 2006. The release version was a debugged draft version. Some minor changes had as well been realised but it did not include the requested updated rainfall data. This was

due to the fact that RBWO did not provide the 2005/2006 rainfall data. The released version of RUBDAv2 is described, tested and evaluated in Chapter 6.

### ***Comparing theory and practice***

This section aims at comparing the proposed development plan with what was achieved in reality: Comparing theory and practice. This should demonstrate whether it can be concluded that the development of RUBDAv2 was conducted as a software development project. The development plan proposed by the software developer was realised at the beginning of 2007 after the development of RUBDAv2 was achieved. The software engineer was involved in the development of RUBDAv1 and v2 and contributed to define the plan used for the development of RUBDAv2. The key variables that were used for the comparison are the temporal division adopted, the allocated time and the real time spent, the content and activities carried out in each phase with a special attention given to validation mechanisms. The proposed and used life cycles were identical as far as the number of phases and the output of each phase were concerned. It involved four phases to produce a paper prototype, a prototype, a draft version and a release version. It is difficult to evaluate the time spent on the different activities as they were defined in the proposed development plan. The activities proposed were: Analysis (1 week), specification (1 week), design (2 weeks), programming (3 weeks), unitary tests (3 days), integration tests (1 week) and validation tests (1 day).

The analysis and specification phases were not conducted as such for the development of RUBDAv2. They had been done for the design and development of RUBDAv1. Some of the project reports produced during the participation phase (see Chapter 4) were reviewed after the first training in order to analyse the requests made by users from a new perspective. This review combined with the analysis of the training outputs were used to design the new interface and components for the production of a paper prototype. These activities lasted one week and can be compared to the four weeks that were allocated for the analysis, specification and design activities.

The programming, unitary tests and integration tests were not conducted as separate activities when the different versions of RUBDA were produced. The interface and the



different sub-models were programmed and tested progressively then integrated into RUBDA and tested again. The fact that the software engineer came to Tanzania only for short missions rendered difficult any estimation of the time spent on these activities. Nevertheless, the time allocated (4 weeks and 4 days) seems rather short compared to the 11 months that separated the start of the design of RUBDAv2 and its delivery to the users. While the work necessary was planned for two software engineers working full time, it was done by one software engineer and the researcher.

The last activity, validation, was planned to last only one day. This seems rather short compared to the two days trainings organised. Participants requested several times for a longer training with more demonstrations and exercises. Comparing the validation mechanisms is probably the most critical issue. We have seen that the number and nature of the phases were similar but the means, the actors involved and the type of validation performed might differ. In the proposed life cycle, each phase (except the last phase) ended up with a validation of the version of the DA produced. The development of RUBDA followed the same logic. The prototype and the draft versions were validated by users but the paper prototype was only validated by project partners.

The validation mechanisms proposed and those applied were very similar. The proposed validation included: 1) Presentations of the project, the GUI and the existing functions, 2) Demonstrations of RUBDA using pre-set scenarios 3) Conducting different types of exercises (initiation and “real-life”) with users and 4) Evaluation of the DA with users’ questionnaires. All these activities were conducted during the trainings.

The main differences between the software project management methods and the development method used for RUBDAv2 concern the documents produced. In the proposed development plan, the progress in the development is guided by documents produced and validated by the project leader concerning all the different components of the software. Design work achieved during each phase before programming starts is used to define output specification. By doing so, developers ensure that the programming work is coherent with the terms of references. It eases the design and development of the different components and their integration in the software. Function analysis and UML modelling allow the visualisation of the functional requirements of a system, including the relationship between the users and the software, the procedures,

the tasks achieved by users or the link between the different components of the software. The GUI specification, the UML modelling and the function analysis were not realised for the development of RUBDAv2. As a result, the new specifications and on-going changes that were made depending on the requests made by users delayed seriously the development and created bugs because they had not been planned and designed properly.

A major difference between the proposed plan and what was actually done concerns the actors involved in the validation process. As shown in Table 15, the only DA users involved in all the phases are the RBWO. The reason for that was that the software engineer believed that developing a tool for such a high number of users belonging to various Ministries and organisations was not feasible. He believed, from his own experience, that a DA should be developed for specific users. Having so many different potential users with different aims and perceptions could only lead to an unfocused design and would result in too ambitious specifications if attempting to satisfy all users. The decision making processes must be clearly defined, well analysed and transform into precise specifications. It implies that the clients should know what they want to do with the DA. In our case, and although the developers attempted to narrow down the variety of users (RBWO and District Councils), we still involved users from many different types of organisations during the design and validation phases. This was an obligation for a project such as RIPARWIN.

Comparing “what should have been done” with what was actually done revealed that the development of RUBDAv2 did implement development methods and a range of approaches derived from/similar to software project management.

## **5.6. Discussion**

RUBDAv1 was centred on the modelling and structure of the interfaces whereas RUBDAv2 was user/problem oriented. The use of methods from software engineering contributed to improve the development of RUBDAv2. In RUBDAv1, the input of data and the display of results did not fit the requirements of users. On the basis of the inputs gathered during the trainings, users were satisfied by the new interface developed for

RUBDAv2. The modifications did not affect much of the hydrological modelling *per se* (apart from the rainfall year starting date, and the use of building blocks to create water demands) but only the way these models interacted with users (through the interface). The shift that occurred between the development of the two versions of RUBDA concerned not only the development method but the whole development approach. The aims, the structure and the Graphical User Interface (GUI) of RUBDA evolved by changing the way users' requirements were taken into account for its design. It implied, as stated by Bell (2001), a shift from the development of the most practical DA (from a technological point of view) to the development of the most appropriate DA (from the users point of view). The main characteristics of the approaches adopted for the development of the two versions of RUBDA are summarised and presented in Table 16.

Project management methods and the use of development cycles to design a product allow users to take decisions, interact with developers and give orientations during the different phases to improve the product. The validation of the different versions of a product benefits to both the users and the developers. The developers and the project leader can evaluate step by step the progress made and avoid going backward and forward. This, nevertheless, was only partly true for the development of RUBDAv2 since there were some changes made to answer users' requests that had not been planned or designed. These changes created bugs and errors that forced developers to go back and reprogram components that had already been validated in previous phases.

Implementing software engineering methods was an attempt to develop a user-oriented DA. RUBDA was meant to target a large variety of users and the fact that developers tried to answer all their requests complicated the development process. The modification of the design and development methods in order to shift from a modelling centred tool to a user oriented tool did improve significantly the usability of RUBDA. As stated by Oxley (2004:1001), research models tend to be model oriented whereas policy models are interface centred. Oxley (2004:1001) insists on the fact that a policy model is "interesting and worthwhile only through its output" as opposed to a research model that is "interesting and worthwhile in its own right" because it is scientifically innovative and/or contributes to improve the understanding of a particular process.

*Table 17: Comparison of the development approaches adopted for RUBDAv1 and RUBDAv2.*

<b>RUBDA v1</b>	<b>RUBDA v2</b>
Research tool Process-oriented tool Model-oriented interface DA most practical to develop (from a technological point of view)	Policy/management tool End user/problem oriented tool User-oriented interface: ease of use, simplicity, transparency DA most appropriate for users
Optimisation of water resources management	Exploration of options, search for acceptable options
Top down Prescription Developers as water experts Managers learn from experts	Bottom up Open and collaborative design Developers as facilitators and knowledge builder based on constructive interactions
“Rational” modelling Myth of managers as scientists taking scientifically sound and rational decisions. Idealised behaviour of users	Confronting actual behaviour and myth allows a new vision of actors’ constraints and objectives.
Decision sciences Normative approach Quest for the best solution	Decision aid sciences Science supports decision making

This shift also required developers and project partners to change their behaviour when interacting with users and conducting the trainings. During the trainings, developers and trainers were more facilitators than experts. As facilitators, they had to create discussions and let users raise their concerns, identify problems and propose ways of improving RUBDA. Facilitators were asking users how best the hydrological model could be used to get as close as possible to their needs instead of concentrating on the needs of these users. This was achieved by organising group work on specific topics and organising discussions and debates about how to model and display components of

RUBDA. This approach proved very efficient for the design of the irrigation building blocks and the water priority and allocation model. During discussions, users explained how these components had to be built and the developers had to find means to transform their requests into a model. Technological choices cannot be made before analysing the decision processes and the requirements of users.

It is this shift in approach that enabled the improvement of RUBDAv2 over RUBDAv1. Software project management provided the framework that forced developers and project partners to get rid of their water experts “cap” and endorse their facilitators’ “cap”. They had to generate discussions and debates, help users express their demand and act as “translators” between users and the programmer. The role of the developer is well described by Roy (1990) who insists on the need for researchers and developers to abandon their strong prescriptive approach justified by a universal rationality in order to understand decisions processes and assist decision making. This statement reflects the changes that occurred for RUBDA which first had to assist the implementation of IWRM and finally concentrated on providing the information required by users for the management of water resources. According to Roy (1993:p21), intervening in a decision process consist rarely in providing a solution to a problem but rather to imagine an acceptable arrangement in a conflicting context. David (1996) adopts Roy’s (1993) point of view and combines it with Hatchuel’s (1994) to demonstrate the role that DAs had in the last decades and that they should shift from constraining<sup>17</sup> tools (prescriptive role) to exploration tools (open design).

In the documents and presentations used during the last two trainings, the aims of RUBDAv2 were to explore options, set and explore water demand and assist users in understanding some key issues such as how to ensure perennial flows, how to reset the water rights or how much irrigation could be done. These aims reflect RUBDAv2’s exploratory nature. They show the willingness of developers to abandon the aim of assisting decisions by searching for appropriate solutions to solve water shortages (i.e optimisation of water resources according to IWRM). The main objective became to develop a tool that could assist decision making by providing means to the users to explore the “reality” and finding acceptable solutions.

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<sup>17</sup> Translated from French « outil de conformation » David (1996 :24)

Although RUBDAv1 was a research tool built to model as precisely as possible the hydrology of the UGRRC and to allow the running of scenarios, the belief that developers would provide clear decision making processes remained. As stated by Malézieux et al. (2001), most researchers and software developers consider users of DAs as scientists searching for the optimised way of using natural resources. This assumption presents a serious advantage when it comes to the analysis of the decision processes and when designing DAs because it limits drastically the number of users' possible choices and strategies. It is this assumption that lead to the development of RUBDAv1 as a research tool that would assist decisions taken by water managers.

The assumption that water managers were taking scientifically sound decisions also entertained the belief that the participation of users during the design phase would allow the identification of these decision processes. This was a source of frustration for developers as these processes could never be defined precisely.

## **5.7. Conclusion**

This chapter reviewed the development of the two versions of RUBDA giving a special attention to the methods used for its development and the impact it had on the interaction between the users and the developers and furthermore the impacts it had on the DA being developed.

The chapter showed that the use of methods derived from software project management improved significantly the usability of RUBDAv2. It did so by improving the interactions between end-users and the developers and the “translation” of these needs into design specifications.

Improving these interactions required developers and project partners to change their behaviour from water expert to facilitators. As facilitators, developers must abandon their prescriptive approach (water experts promoting IWRM) and adopt an open and collaborative design approach building upon their interactions with users to design the DA. Developers are then in a position of searching to adapt and create the DA that is

most appropriate for users instead of concentrating on the modelling. This led to the shift from a modelled centred RUBDAv1 to a user oriented RUBDAv2.

Although IWRM was the overall framework guiding WRM in sub-Saharan Africa, the mismatch between users' needs and RUBDAv1 demonstrated that applying the requirements of IWRM to the design of a DA resulted in the development of a research DA but not to the development of a management DA that fits the water resources managers' operational context.

This results from the split that exists between IWRM as a theory described and promoted by the international community on the one hand and the operational reality as performed by local governments and river basin authorities on the other hand.

In the case study, users of RUBDA do not act as scientists searching for the optimised way of using natural resources. Water managers in sub-Saharan Africa operate in a context where they have little room of manoeuvre as managers but instead have to deal with the set of local, community based practices that are normally determined by local customs, traditions and culture of the water users.

To respond to users' needs, RUBDAv2 aimed at assisting decision making by providing users means to explore the "reality" and provide "acceptable" solutions. This can be opposed to the IWRM theory that searches for the optimised potential of valuation of water resources considering the socio-economic and environmental dimensions. In the case study, water resources managers searched for an acceptable share of the scarce water resources between uses. The DA must therefore offer means of exploring the different options managers have and the impact of these options.

The next chapter presents tests and evaluates RUBDAv2 in order to assess its ability to effectively assist water managers in the UGRRC.

## Chapter 6 - Testing RUBDAv2 using the RBWO vision

This chapter examines the ability of RUBDA to assist the River Basin Water Office (RBWO) in effectively managing water resources. The aim is both to demonstrate the functionalities proposed by RUBDA and explore the potential impacts that the RBWO's "vision" would have on the hydrology of the Upper Great Ruaha River Catchment (UGRRC). The "vision" represents the set of water allocation measures and objectives that the RBWO intend to put in place in order to restore year round flows in the Ruaha National Park. The final version of RUBDA v2 (as it was when finally released to the RBWO) and its models, structure and data are tested using case study scenarios. The limits of the RBWO vision and of the functionalities of RUBDA are also discussed. The output of the evaluations of RUBDAv2 will contribute to answering the research question: Can existing development methods be used to develop a DA that fits the operational context of water resources management?

### **6.1. Introduction**

In the previous two chapters, the design and development process of RUBDA has been described in detail, focussing on the effectiveness of user participation and on the interactions between the users and the Decision Aid (DA). This chapter focuses on the tool itself, in order to present and evaluate the outputs of the design phase. The aim is to assess whether the efforts put into the development of the tool generated the intended purpose, i.e. that a useful and usable DA would be delivered to the RBWO. During the various training sessions and tests held with users (see Chapters 5 and 6), the user-friendliness and the functionalities of RUBDA v2 were tested, modified and improved in accordance with users' comments and observations of their use of the tool during the training sessions. The aim of this chapter is to examine whether and how the DA is appropriate for the RBWO and therefore assess the DA fit the operational context of water resources management. Doing this required the following steps:

1. The different components of the DA were scientifically assessed, especially hydrological modelling, by testing the various models and by running current and natural conditions (no human intervention) scenarios;



2. A basin vision scenario was run as a role playing game, by trying to endorse the role of a manager from the RBWO to test the usefulness of RUBDA; outcomes were analysed against intended objectives.
3. An analysis of RUBDAv2 was performed using the evaluation grid proposed by Mysiak (2005).

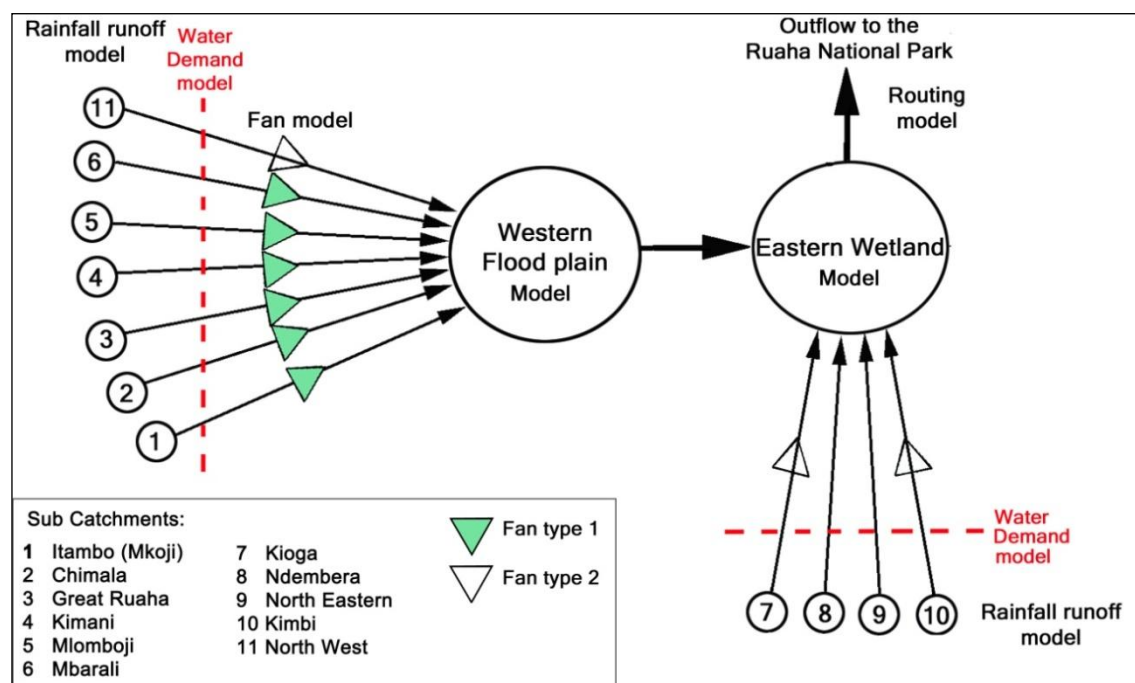
Section 6.2. presents the different components of RUBDA v2 and the outputs of some of the evaluation tests that were run on these components. The tests presented in the sub-sections 6.2.6, 6.2.7 and 6.2.8 were run by the modellers involved in the SMUWC project, the other tests run on specific models and on the whole of RUBDA were done by the researcher. Section 6.3. presents the parameters finally chosen to run three scenarios which are used to evaluate RUBDA. Section 6.4. presents the results of these scenarios and shows how on the basis of the scenarios RUBDA can be used by end users in the RBWO. Finally, in Section 6.5. the evaluation grid proposed by Mysiak (2005) is used to evaluate RUBDA v2.

## **6.2. RUBDA v2 hydrological components**

This section describes the different models and components of RUBDA v2 and includes some tests run by the modellers from the SMUWC project to show the accuracy and limitations of the hydrological models. The effects of these limitations on the results generated by RUBDA v2 are discussed.

The different components that comprise the hydrological modelling part of RUBDA v2 are shown in Figure 27. The hydrological modelling in RUBDA v2 comprises three main components: the sub-catchments (SC), the Western Flood Plain and the Eastern Wetlands. Sub-catchments 1 to 6 and 11 feed into the Western Flood Plain. This flood plain has an area of a few hundred km<sup>2</sup> during the wet season when it is flooded. The water exiting the Western Flood Plain feeds into the Eastern Wetlands through a well defined channel. Sub-catchments 7 to 10 also feed into the Eastern Wetlands. Although the runoff generating catchment area of the Western Flood Plain and that of the Eastern swamp are almost the same (about 7,500 km<sup>2</sup>), the runoff generated by the eastern part is about one third of the runoff generated by the western part (SMUWC, 2001).

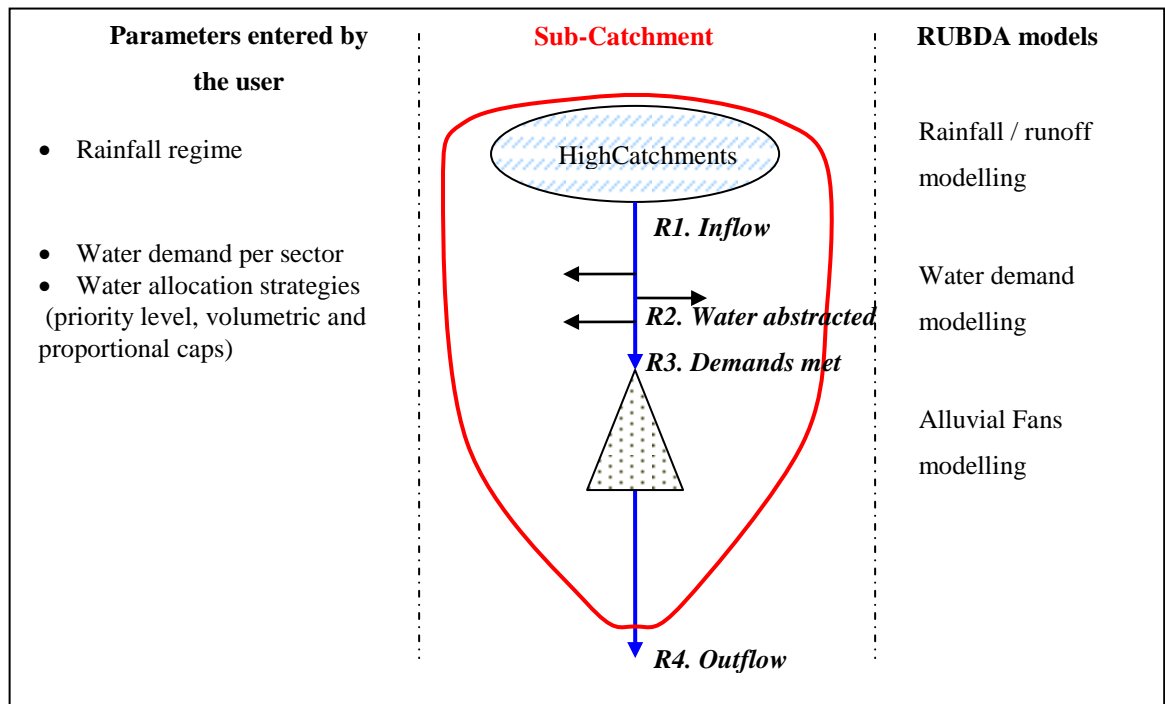
Figure 27: Schematic diagram of the components of the hydrological modelling of RUBDA v2.



RUBDA aims to support the RBWO in its mission to manage the water resources of the UGRRC. To do this, it focuses on generating information at the sub-catchment scale to provide the RBWO with some means of issuing water permits to sub-catchment (SC) level water users associations. As described in Chapter 5, representing the UGRRC using the sub-catchment scale and offering means to run scenarios on a specific sub-catchment was one of the most important requirements of the end-users. The RBWO requested that two of the 11 sub-catchments used in RUBDA be redefined and divided into six smaller sub-catchments. Indeed the RBWO identified 15 sub-catchments as being a more appropriate scale for managing water resources in the UGRRC. The two sub-catchments used in RUBDA that do not fit the ones identified by the RBWO are the Itambo and the Western sub-catchment. The sub-catchment scale was used in RUBDA to provide water availability and water uses, and the results are given at the SC scale. The desire was for RUBDA to provide the RBWO with a means of assessing the impacts of different water use strategies at the sub-catchment level, i.e. WUAs, by allowing the user to modify demands as well as allocation strategies and to assess their impact on the downstream hydrology.

Within RUBDAv2 the sub-catchments are modelled using three different models; namely the rainfall/runoff, demand and alluvial fans models. The water demand model is combined with the water allocation strategy model to simulate the water abstraction and generate the downstream flows into the fans. The structure of the sub-catchment as modelled in RUBDA v2 is shown in Figure 28. The input parameters that can be modified by RUBDA users are the rainfall regime and the water demands for the specific sub-catchments and the water allocation strategies (priority level, proportional and volumetric caps of water demand type). The input and output data for each sub-catchment are displayed on a single window (see section 6.4.1).

*Figure 28 : Schematic diagram of the components, inputs and outputs parameters of sub-catchments*



RUBDA v2 provides a means of working at the UGRRC scale by using the “all SC” window (see Figure 29) or at the sub-catchment scale by using the SC window (see Figure 30). The water allocation strategy tool is added to the three models. This allows the user to define water allocation strategies at the UGRRC scale. The strategy defined at the UGRRC scale has an impact on water uses at the sub-catchment level.

Figure 29 : Screen shots of the “all SC” window

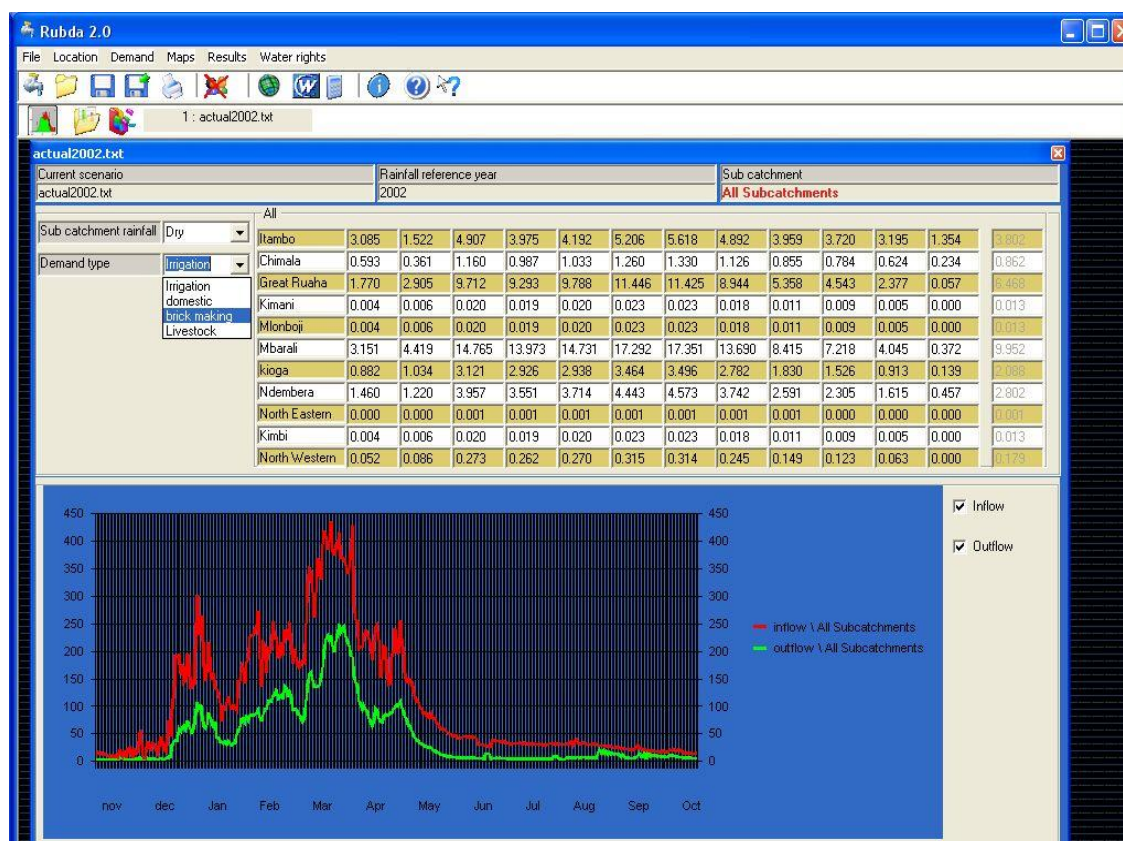
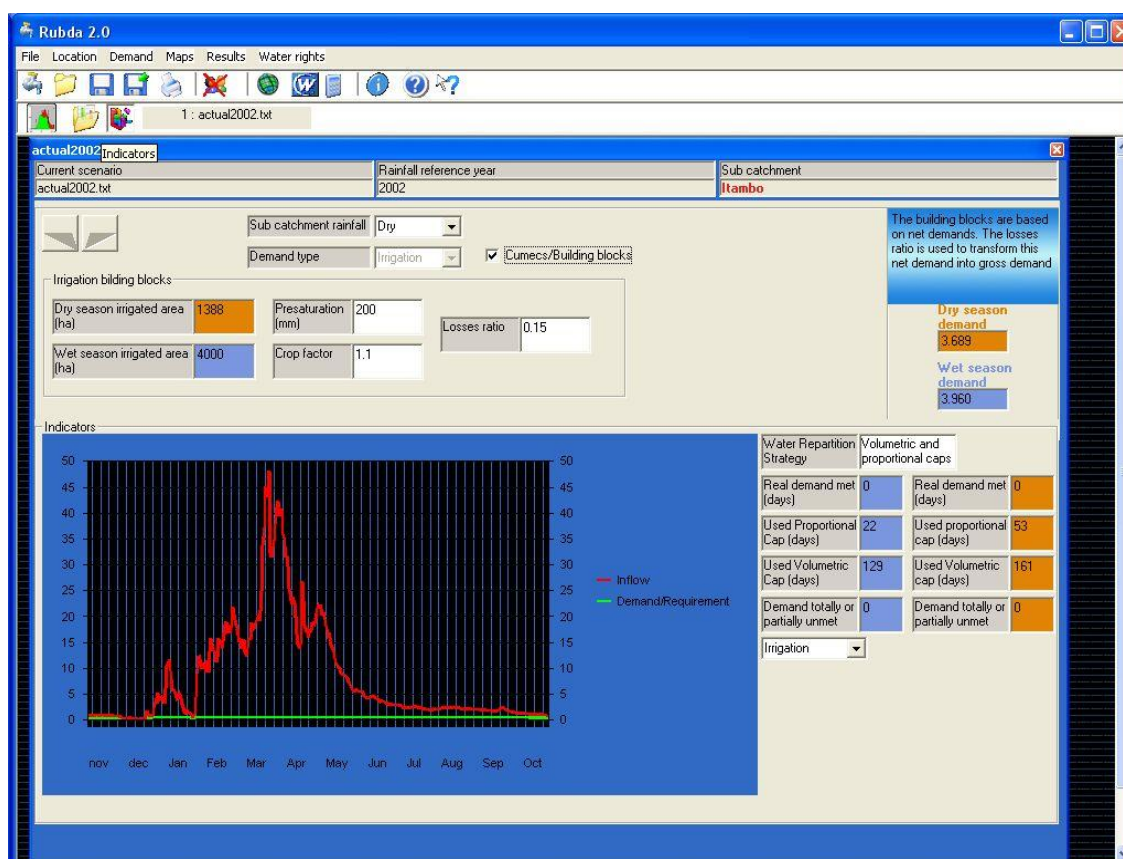


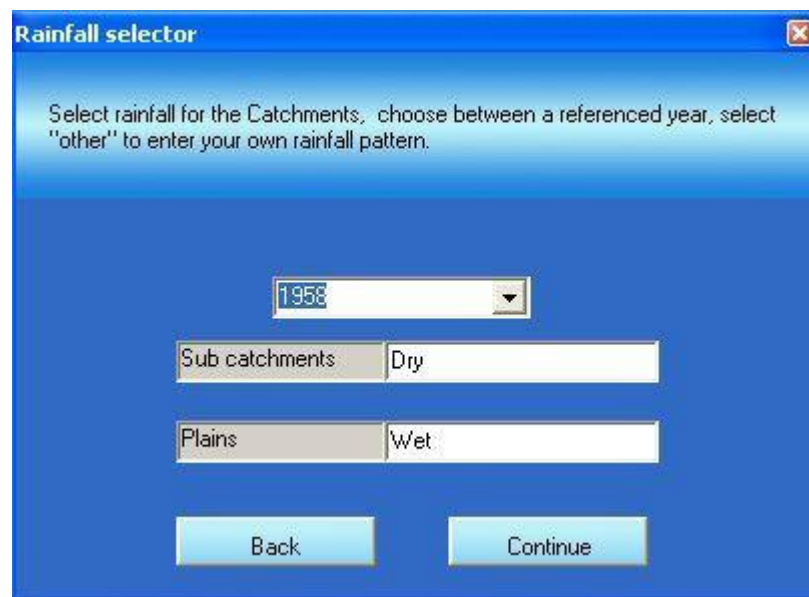
Figure 30: Screen shot of the specific SC window



### 6.2.1. Rainfall data

RUBDA v2 includes a rainfall selector window where the user is asked to select the rainfall regime for the plains and the higher catchments (see Figure 31). To save time when running RUBDA v2, the rainfall/runoff model was removed and the runoff text files corresponding to the five rainfall regimes for the 11 sub-catchments were added. Thus when the user chooses a rainfall regime, the rainfall runoff model does not run: RUBDA just picks the relevant runoff files corresponding to the rainfall regime. This decision was motivated by the limited number of years that were selected to represent the different rainfall regimes occurring in the UGRRC. Following the interviews and training workshop (see Chapters 4 and 5) the historical rainfall records in the catchments were ranked from very wet to very dry and the rainfall record of a specific year was chosen to represent each category (see below).

*Figure 31 : Screen shot of the RUBDA v2 rainfall selector window*



Rainfall selector

Select rainfall for the Catchments, choose between a referenced year, select "other" to enter your own rainfall pattern.

1958

Sub catchments Dry

Plains Wet

Back Continue

An unweighted average of station data was used to estimate time series of Average Daily Rainfall (ADR) for each Sub-Catchment. To allow for the high variability in rainfall over the basin, ADR was calculated for two parts of the catchment; for the higher part of the sub-catchments (mountains) and the plains. Rainfall stations located north of the Iringa-Mbeya road (see Figure 8 in section 3.4. ) and at an altitude of less than 1200 m asl were considered as representative stations for the estimation of the ADR of the plains. 70 stations for the years 1954 to 1998 and 13 stations for the years

1999 to 2003 were used to estimate the ADR in the higher part of the sub-catchments, 13 stations for the years 1954 to 1998 and three stations for the years 1999 to 2003 were used to estimate the ADR of the plains. Mean Annual Rainfall (MAR) for the higher part of sub-catchments (an average over the 11 sub-catchments) and the plains was then estimated. Frequency analyses using MAR was then conducted to classify the 50 years of rainfall data into five categories of rainfall years, namely very dry, dry, normal, wet and very wet years. The five rainfall regimes were defined using the exceedance probability as shown in Table 18.

*Table 18: Representative years for rainfall types and their corresponding Mean Annual Rainfall*

No	Rainfall regime	Range Exceedance probabilities (%)
5	very wet	0 - 5
4	wet	5 to 25
3	normal	25 to 75
2	dry	75 to 95
1	very dry	95 to 100

\* Mean annual rainfall of selected rainfall stations

The rainfall regime can be chosen by the user when creating a scenario (in this case it is the rainfall regime of the chosen year that is used), or the user can define the rainfall regime for the plains and for the SCs. The rainfall regime can also be modified when running the scenarios, either on the “all SC” or specific SC window.

The runoff for each of the SC was calculated using the rainfall data of the representative year (Table 19) and the data from the rainfall stations located within or close to the sub-catchment. The rainfall data of each sub-catchment is generated by averaging the daily data of the stations located near to it. As a result, for example, a year classified as dry when considering the whole of the UGRRC might be classified as normal or even wet if the frequency analysis is undertaken for one sub-catchment. This approach was adopted when users raised the fact that the spatial distribution of rainfall varies a lot in the UGGRC, and that it would have been wrong to assume that all sub-catchments experience the same rainfall patterns.

The observed spatial variation between the different sub-catchments is even greater when considering the differences between the plains and the high part of the sub-

catchments. Because of these variations, and because users requested that the rainfall pattern of recent years be included, the rainfall selector module was developed to offer its users the choice between the following years:

*Table 19: Rainfall pattern in the plains and the sub-catchments*

Year	Sub Catchments Rainfall regime (Mountains)	Plains Rainfall regime (Fans, irrigated fields, wetlands)
1958	Dry	Wet
1963	Very Wet	Very Wet
1968	Wet	Very Wet
1984	Wet	Normal
1985	Normal	Normal
1988	Dry	Dry
1989	Normal	Wet
1994	Normal	Normal
2000	Very Wet	Very Wet
2001	Very Dry	Very Dry
2002	Dry	Dry
2003	Very Dry	Very Dry
2004	Very Dry	Normal
Other	Choice of the user	Choice of the user

The three scenarios that are presented in the next sections of this chapter use the rainfall pattern of the year 2002: dry for both the plains and the sub-catchments. The rainfall records used for a dry year are those of 1988 for the plains and 1958 for the higher sub-catchments.

### ***Spatial variation of rainfall: The Kimani sub-catchment example***

To illustrate the spatial variations existing in the UGRRC, the rainfall regime classification of the Kimani sub-catchment was analysed in order to determine the specific rainfall regime of the year 2002. Figure 32 shows the historical annual rainfall from 1962 to 2004, taken from the available rainfall data for three stations located within and just outside of the Kimani sub-catchment boundary. Frequency analyses of the mean annual rainfall was also realised using the Rainbow model from the University of Leuven (Raes et al. 2006), and the mean annual rainfall data were classified using their probability of exceedance. The rainfall categories were defined using the same



range of exceedance probabilities as for the whole UGRRC (see Table 18). Historical mean annual rainfall is compared to the different rainfall regimes in Figure 32

*Figure 32: Historical mean annual rainfall for the Kimani sub-catchment compared to the rainfall regimes*

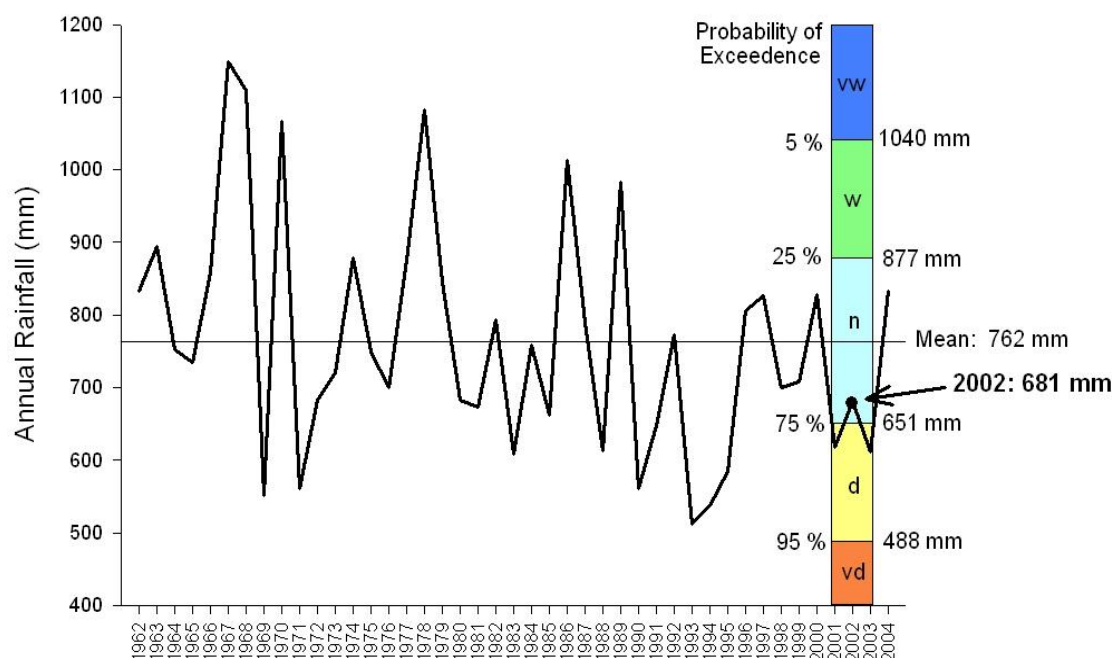


Figure 32 shows that although the whole UGRRC is classified as dry for the year 2002, the rainfall for the same year is classified as normal for the Kimani sub-catchment. It can however be noted that the annual rainfall for 2002 (681 mm) is only just above the upper limit of the dry category (651 mm). The differences that might occur between the rainfall regimes determined for the whole UGRRC and those of the sub-catchments will have an impact when comparing the simulated flows to the observed flows in the sub-catchments (because of the rainfall variation between the mountainous areas and the plains) and to a lesser extent in the downstream locations.

### 6.2.2. Rainfall runoff modelling

Only one third of the total area of the 11 sub-catchments is gauged. One sub-catchment is totally gauged (SC 6), eight sub-catchments are partially gauged and three are not gauged. There are 13 gauged catchments in the basin (that were later transformed into 11 sub-catchments in RUBDA) used to model the rainfall runoff. All of them are



located in the higher part of the 11 sub-catchments. Moreover, there is a substantial amount of missing data for most of the stations' daily gauges. It was therefore necessary to reconstruct the missing river flow data for the 13 gauged stations. This reconstruction was achieved firstly by using cross-correlation between the two neighbouring stations to fill missing data, and secondly by rainfall-runoff modelling (Linear Perturbation Model) to fill in any remaining missing data. Proportionate scaling was used to estimate the runoff generated from the ungauged parts of the 11 SC. Because most of the gauged catchments are located in the higher part of the 11 SC where the rainfall is higher than in the plains, the estimated runoff from the SC is likely to be an overestimate (SMUWC 2001).

The three ungauged basins (sub-catchments 9, 10 and 11) represent two-thirds of the ungauged area. For these sub-catchments the runoff data were generated by using rainfall data available for the sub-catchments and runoff generating parameters (soil and land cover) from gauged catchments presenting similar characteristics.

### **6.2.3. Water demand and use**

The principal water demands within the basin are wet and dry season irrigation, livestock watering, domestic supplies, and maintenance of the aquatic ecology of the Eastern Wetlands and the RNP. The latter two demands represent the environmental sector, thus are not modelled as water demand sectors in RUBDA. Their demand for water is modelled as environmental flows requirements; therefore RUBDA can indicate whether these requirements are met or unmet. Another important water demand not mentioned above is linked to brick making activities, which although not requiring a substantial amount of water, is critical to sustain the livelihoods of certain populations living in the UGRRC. The demand for water from the two hydropower stations, namely the Mtera and Kidati hydropower dams, are also important but these are located downstream of the UGRRC and so are not modelled in RUBDA v2.

The various water demands – apart from those deemed environmental – are lumped together at the sub-catchment scale and expressed as monthly averages of water abstracted in  $\text{m}^3 \text{s}^{-1}$ . These monthly averages represent the gross water demand of each

sector. However, whether the demand is met is not guaranteed because it depends on the supply of the available amount of water in the sub-catchment.

The water demands are abstracted in the different sub-catchments between the higher part of the sub-catchments where the river flows are generated and the alluvial fans located in the plains. As discussed in Chapter 4, in RUBDA v1 water could be abstracted at several points in the sub- Catchments and in other parts of the UGRRC (e.g. the wetlands or the RNP) yet participants asked to be able to play with the water allocated to each sector. In RUBDA v1, the demand module existed in six locations of the UGRRC but the default demand was set to zero in all but one location, upstream of the fan in the SC. Because almost all water uses (and especially irrigation) are located upstream and in the fans, and because the training participants never attempted or asked to modify the demand in other locations, it was decided to remove the possibility of creating water demands downstream of the SC. The training participants instead requested to be able to define water allocation strategies (using priorities and restrictions) and that water uses should be expressed in terms of irrigated area or human population. The upgrading of the water demand module, if applied to the six locations, would have rendered the modelling and computing very complicated. As a result:

- Water demand could only be modelled in the sub-catchments and not around the wetlands or in the RNP. This is not a significant constraint as most of the irrigation schemes and villages are located within the sub-catchments.
- "Building blocks" were created so that water demand could be expressed using the monthly average abstraction rates or using parameters such as irrigated areas or human and livestock population;
- A new water allocation strategy module was added.

There are consequently two ways of entering water demands in RUBDA v2; firstly by entering monthly averages of the water abstracted (in  $\text{m}^3 \text{s}^{-1}$ ) by each water use for each sub-catchment, and secondly by modifying the building blocks parameters. The water demand is calculated in RUBDA v2 using the "building blocks method": In other words, the water abstracted is considered a function of area under irrigation, human population, livestock population and losses. There are two types of building blocks: The first one is used for domestic needs, livestock or brick making water demands; The second one is designed for the agricultural sector and is much more complex. When

creating a new water demand, the user is therefore asked to choose between these two types of building block methods. For instance, if a user adds a new water demand such as fisheries, the first type of water demand will be appropriate.

The first type of building blocks is used for domestic, livestock and brick making water uses. The monthly average of water abstracted is calculated by multiplying the population by the water use rate per day and by the water losses rate as indicated below. Building blocks type 1:

$$(a) \quad Q_{\text{abst.}} = P * W_r * L$$

where:  $Q_{\text{abst.}}$  is the monthly average of the water demand of a specific water use

$P$  is the number of units (population, number of livestock, number of bricks, etc.)

$W_r$  is the water abstraction per unit per day

$L$  is the losses, used to transform the net demand into gross demand

The second type of building block was developed to estimate the water demand of the irrigation sector. The calculation of the monthly average irrigation water demand is estimated using the dry season and wet season irrigated areas. The model developed is a simplification of the Irrigation Productivity Model (IPM) developed by the RIPARWIN project. The IPM is an Excel based model determining annual irrigation impact, irrigation efficiency and irrigation productivity. The modelling is based on gross and net demand of water for rice, non-rice and other water uses during both the dry and wet seasons. Different management factors controlling irrigation practices are considered in order to cope with the current practices. The effects of the following management practices were considered:

- Availability of surface water and rainfall upon the timing and rate of transplanting;
- Flooding of fields at the beginning of the season (soil water storage);
- Differing practices upon the depth of standing water in bounded plots;
- Dynamic conditions of runoff from irrigation systems as the wet season progresses;
- Possible release of water at the end of a season when fields are drained;

- Nature and scale of dry-season irrigation and domestic abstraction upon river hydrology;
- Differing cultivation and calendar practices - such as nurseries in September;
- Post-harvest continued wetting of fields during the dry season;
- Balance between rainfall and evaporation upon net water demand.

The Irrigation Productivity Model was simplified to develop the building blocks for the irrigation sector and to fit the requirements of the users without becoming too complex. The simplified model was demonstrated and validated during the training workshops.

Building blocks type 2:

$$(b) Q_{\text{abst}} = (1 / (n * 86400)) \times (B \times P \times 10 + (E * CF) + WL + S - R) * (1 + L) * (SI - B) * 10$$

where:  $Q_{\text{abst}}$  is the monthly average of the water demand for the specific water use

N is the number of days of the considered month

B is the added irrigated area of the considered month

P is presaturation

E is evaporation

CF is the crop factor

WL is the water layer per month

S is seepage

R is monthly average rainfall

L is system losses not recovered

SI is the irrigated area

Before calculating the amount of water abstracted, the monthly parameters B and SI were calculated based on the DSI (the dry season irrigated area, in October) and the WSI (the wet season irrigated area, in February).

Table 20 shows the calculations realised to estimate SI and B; these calculations are based on the model developed by RIPARWIN.

Table 20: Intermediate calculations for SI and B

Months	Irrigated Area (SI)	Added irrigated area per month (B)
Nov	$DSI + (WSI - DSI)/4$	SI Nov – DSI
Dec	$SI_{nov} + (WSI - DSI)/4$	SI dec – SI nov
Jan	$SI_{dec} + (WSI - DSI)/4$	SI jan – SI dec
Feb	WSI	SI feb – SI jan
Mar	$WSI - (WSI - DSI)/8$	SI mar – SI feb
Apr	$SI_{mar} - (WSI - DSI)/8$	SI apr – SI mar
May	$SI_{apr} - (WSI - DSI)/8$	SI may – SI apr
Jun	$SI_{may} - (WSI - DSI)/8$	SI jun – SI may
Jul	$SI_{jun} - (WSI - DSI)/8$	SI jul – SI jun
Aug	$SI_{jul} - (WSI - DSI)/8$	SI aug – SI jul
Sep	$SI_{aug} - (WSI - DSI)/8$	SI sep – SI aug
Oct	DSI	SI oct – SI sep

The model used to build the irrigation (water demand of type 2) building blocks is fairly complicated; therefore to simplify the users' tasks, some of the parameters were fixed and only a few of them are left for the user to set. The choice of the parameters to be fixed was decided during a RUBDA training workshop held in Iringa in June 2006. These parameters are the dry and wet season irrigated areas (DSI and WSI), the presaturation (P), the water layer (WL), and the losses (L). The plains rainfall and evaporation data are used for the irrigation model. The crop factor was set to 1.1 which corresponds to the rice crop factor, and the seepage was fixed to 30 mm based on the simulation done with the IPM model.

#### 6.2.4. Default water demands

The data entered into RUBDA as “default” is a compilation of data from different sources. It represents the water uses estimated for the years 2002 and 2003. The water use parameters used in the building blocks were obtained from four different sources, as presented in Table 21. Nevertheless, most of the data were obtained from a study conducted under the RIPARWIN project that aimed at estimating the water productivity for the different water sectors in the UGRRC. The water productivity study was conducted for the years 2002/2003.

*Table 21: Sources used to generate the default water demand data for RUBDAv2*

<b>Source</b>	<b>Report</b>	<b>Type of information</b>
SWMRG-FAO STUDY	Comprehensive Assessment Of Water Resources Of Mkoji Sub-Catchment, Its Current Uses And Productivity (based on 2002/03 survey)	Cropped area, cropping patterns and sequences, livestock population, brick making activities and current water uses in MSC (2002/03).
SMUWC	SMUWC database	Ward human population, areas under irrigated agriculture.
RIPARWIN	Water Productivity Table and Analysis	Irrigated area, estimated production of bricks, livestock populations and water uses rates for the SC (other than MSC)
National Census	2002 Tanzania National Population Census	Human population

### ***Domestic water demand***

The domestic water demand is calculated in RUBDA v2 using building block type 1. The default population figures were obtained from the 2002 Tanzanian National Population Census, and the water consumption per capita and per day was obtained from research conducted as part of a Soil and Water Management Research Group and FAO project financed by the government of Netherlands (called SWRG/FNPP project). In this project, the domestic water consumption of some sample households in the Mkoji sub-catchment was determined, and these figures were then used to generate the water demand for the other sub-catchments. The average water demand per day per inhabitant is set to 30 litres.

### ***Livestock***

The average number of livestock owned per household was converted into Livestock Units by applying the Tropical Livestock Units (TLUs), conventionally used for sub-Saharan Africa. According to ILCA (1990), Jahnke (1982) and Williamson and Payne (1978) the units are given as follows: an adult cow is equivalent to 0.7 TLU; a donkey to 0.5 TLU; a pig to 0.3 TLU; goats and sheep to 0.1 TLU; and poultry to 0.01 TLU. The calculation of water use by livestock was mainly based on estimates obtained from the SWMRG-FNPP study and through discussions with herders and owners that revealed that water consumption by cattle (250 kg) is about 40 litres per day in the dry season when forage has low moisture content, and 20 litres per day during the rainy

season. This daily water consumption was used to generate the average TLU water consumption. The study extrapolated the 2002 census results for the number of households in Mkoji sub-catchment to get the estimated total number of TLUs in the sub-catchments using the average number of TLUs per households obtained during the sample survey.

During the dry season, there is a shortage of pasture and water resources to support big herds of livestock across most of the catchment. Those with large cattle herds also migrate with their 'shoats' (sheep and goats). However, building block type I does not allow different numbers of units (here the livestock population) to be entered for the wet and dry season; hence water demand for the livestock sector is overestimated during the dry season.

### ***Brick making***

Brick making water demand figures were obtained from the Water Productivity study conducted by the RIPARWIN project. Results from the questionnaire survey and focus group discussions undertaken by the SWMRG-FAO project in the Mkoji sub-catchment were used to determine the productivity of water for brick making in other sub-catchments of the UGRRC. During the SWMRG-FAO study, the Mkoji sub-catchment was divided into three zones: Upper, middle and lower. The intensity of brick making activity varies between these different zones, hence the other sub-catchments of the UGRRC were categorized as being equivalent to the upper, middle and lower zones of the Mkoji sub-catchment, and the parameters from the respective zones were used in calculating the productivity of water in brick making. The basic parameters used in calculating the productivity of water in brick making are shown in Table 22. The amount of water consumed is the net volume used in making bricks.

About 35% of the total number of households in Upper Mkoji sub-catchment, and 25% both in Middle and Lower Mkoji sub-catchment are involved in brick making. The average number of bricks made per household per annum was estimated as 971, 507, and 422 for Upper, Middle, and Lower Mkoji sub-catchment respectively.

Table 22: Basic parameters used in calculating the productivity of water in brick making (RIPARWIN project)

Mkoji SC Zones	Number of bricks produced per person per annum	Water consumed per person per annum to produce bricks (m <sup>3</sup> )
Upper	206	0.514
Middle	140	0.351
Lower	73	0.183
Average (MSC)	140	0.349

On average 1 m<sup>3</sup> of water produces about 400 bricks. Brick making in the UGRRC is normally a dry season activity but because the number of bricks produced cannot be different for the dry season and the wet season in the building blocks, the wet season water demand for the brick making sector is overestimated. However, this overestimation has little impact on the hydrology of the sub-catchment because the amount of water used by the brick making sector is almost insignificant when compared to water demand in other sectors.

Table 23: Default parameters of the building blocks in RUBDA v2 for the domestic, livestock and brick making water demand sectors.

	Human Population	Number of Livestock units	Number of Bricks made
Itambo	73,000	154,000	10,530,000
Chimala	7,443	120,000	4,390,000
Great Ruaha	4,267	70,000	2,515,000
Kimani	2,450	40,000	1,444,000
Mlomboji	100	1,300	44,000
Mbarali	23,256	400,000	13,770,000
Kioga	23,000	370,000	13,590,000
Ndembera	11,445	200,000	6,746,000
North eastern	0	0	0
Kimbi	1,000	0	0
North western	73,000	154,000	10,530,000
Total (for 11 SC)	218,961	1,509,300	63,559,000



## ***Irrigated crops***

The irrigation water demand is calculated in RUBDA v2 using building block type 2. The dry season and wet season irrigated area were obtained from the Water Productivity study conducted by the RIPARWIN project. The dry season irrigated area was estimated to be the same whatever the rainfall regime. The dry season irrigated areas (DSI) and wet season irrigated areas (WSI) for the various sub-catchments are presented in Table 24. The WSI varies quite considerably as compared to the DSI.

*Table 24: Dry season irrigated areas (DSI) and wet season irrigated areas (WSI) (ha) for the various rainfall regimes.*

SC	DSI Dry season irrigated area	VD WSI Wet season irrigated area for a very dry year	D WSI Wet season irrigated area for a dry year	N WSI Wet season irrigated area for a normal year	W WSI Wet season irrigated area for a wet year	VW WSI Wet season irrigated area for a very wet year
Itambo	1388	4000	6912	9552	12192	12308
Chimala	240	1000	1963	2380	2797	3021
Ruaha	52	3000	3561	4100.5	4640	5169
Kimani	46	1100	2292	2298	2304	4233
Mlomboji	0	20	20	20	20	22
Mbarali	240	6203	8000	9000	10000	13000
Kioga	164	3360	3802	4634	5466	7568
Ndembera	449	3500	3933	4217.5	4502	4567
North east	0	0	1	1	1	1
Kimbi	0	20	28	29	30	31
North west	0	270	270	271.5	273	273
Total	2517	21120	28985	34806	40627	45903

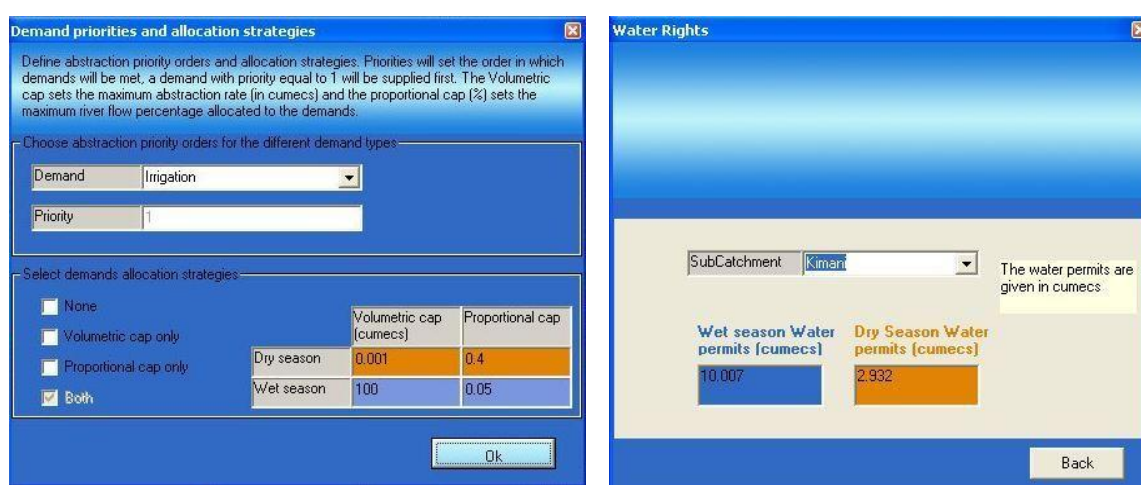
### **6.2.5. The Water Demand priority and allocation strategy module**

The aim of this module is to provide the user with means to apply specific water allocation strategies in the sub-catchments of the UGRRC. The strategy is based on two main tools: firstly the **priority level of the water demand sector** which defines the order in which the sectors will be supplied water (the sector with the highest priority level is supplied first); and secondly the **restrictions** that need to be applied to the same sectors. These restrictions are of two types: The maximum volumetric water abstracted, and the maximum proportion (percentages) of river flows that can be abstracted. The

restrictions are to be set for the dry season and the wet season. The user can choose between applying one, both or none of the two types of restriction.

The module was built following a request made by training participants that it should be possible to control the water allocated to the various sectors in terms of maximum water abstracted or as a percentage of the water available. The request concerned the water allocation for the whole UGRRC, but it later became clear that it would have been more useful to enable users to set these maximum rates at the sub-catchment level. This would have provided the users with another means for testing water allocation strategies specific to each sub-catchment. This is exactly what the RBWO was trying to do in its vision where water allocation strategies and objectives differ between sub-catchments.

*Figure 33: Screen shots of the Water Demand priorities and allocation strategies window (left) and of the Water Rights window (right). (Note: the second window is not referred to in the text)*



Setting a priority level for the different water sectors is another way of fixing water allocation strategies. However the main reason why this was added to the module was because of modelling constraints. Indeed, the water demand of each sector is abstracted at one point of a sub-catchment's river. The water abstracted by each sector depends on the water available in the river after water demands with higher priority levels have received their allocated water. It was therefore necessary to know which water demand was supplied first, because otherwise the total water demands might exceed the water available in the river.

The priority level set by the user should reflect this water allocation strategy. For instance, the priority order might be defined according to:

- The economic value of water, if the strategy is based on the principle that water is an economic good and water must therefore be used by the sectors with the highest monetary production;
- The social value of water uses, where water is allocated to those uses benefiting the most people, and especially the most vulnerable users;
- The national development strategy, for instance if there is an objective of developing a particular sector, such as agriculture, industry or the environment;
- The national priority level of the sector (as it is, for example, defined in the South African Water Policy that ranks uses of water for domestic needs first, followed by agriculture, mining and other uses).

The priority level of each sector can be modified by the users, including for new water uses created by the users. By default, in RUBDA v2, the sectors are ranked as follow:

1. Irrigation
2. Domestic needs
3. Livestock
4. Brick making

If and when a new water demand is created it is given the lowest priority level.

Although ranking water uses according to their priority level represents an interesting manner of testing water allocation strategies, it does not reflect the reality in the UGRRC, where upstream users abstract water first, leaving a certain share of water for downstream users. The priority level approach implies that water abstractions are guided by objectives set at the catchment level regardless of the upstream/downstream hierarchy within that sub-catchment. Such an ideal scenario is far from reality. The way the module was built is linked to the way water abstractions are modelled in RUBDA, that is, water abstractions are lumped by sector and subtracted from the river flow in one particular location of the basin. This characteristic is an advantage if RUBDA is considered to be an exploratory tool for managers for testing water allocation scenarios. However, it strongly limits the use of RUBDA as a deterministic model.

The way restrictions were modelled (volumetric and proportional caps) is directly derived from a conceptual framework that is being explored by the RBWO as a possible way of allocating water in the catchments. The framework arose from the specific challenge faced by water managers, namely that of tackling the on-going competition between formal and informal legal agreements. The framework attempts to provide water managers, in particular those of the RBWO, a practical approach to managing water resources. Lankford and Mwaruvanda (2005) provide a synthesis of the framework that would allow RBWO to define a water allocation strategy that can suit the legal, institutional, infrastructural and geographical contexts. One of the main assumptions on which the framework is based is that there is a clear division between the management of water during the dry and the wet seasons. Furthermore, Lankford and Mwaruvanda (2005) argue that although there is not an exclusive division between more formal water rights and informal customary agreements, water rights should be used during the wet season whereas customary water agreements are better suited to dry season conditions. This implies that water rights represent access to water quantities as measured by flow rates (e.g. litres/second) and that customary water agreements relate to access to water quantities described by an approximate share of the available water (e.g. “about half of what is present in the stream”). Lankford and Mwaruvanda (2005:2) add that “these assumptions are valid because formal rights are denominated in volumetric terms while customary agreements in their original form (an important distinction since customary rights can be transmuted during formalization procedures into volumetric measures) are founded on a notion of access to an (unmeasured) quantity of water, combined with the notion that not all the water can be abstracted from a stream or irrigation channel”.

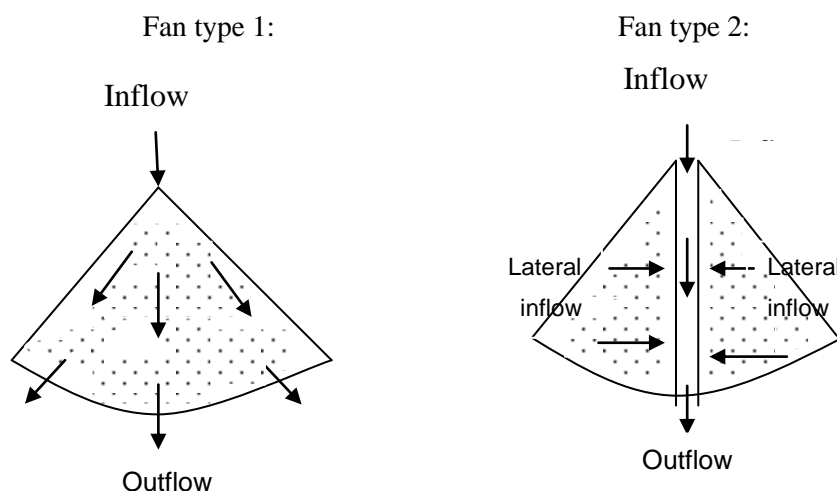
#### **6.2.6. Modelling of alluvial fans**

The rivers of 9 of the 11 sub-catchments flow, after water is abstracted for irrigation and other water uses, through or over an alluvial fan. The rivers flow through two types of fans. Type 1 fan is one in which the river spreads over the fan, whereas Type 2 fan is one in which the river passes through the fan but in a definite channel. Fan types are shown schematically in Figure 34.

Only one of the seven rivers that feed into the Western Flood Plain spread over the fans. The other six simply pass through the fans and join each other before they enter the channel that connects the Western Flood Plain and the Eastern Wetlands. Only two of the four rivers that feed into the Eastern Wetlands flow in a well defined channel. The other two rivers spread over two large alluvial fans (area estimated to be 14 km<sup>2</sup>). When water is spread over a large fan its water is considered to be lost in evaporation and through infiltration.

Type 1 fan model was developed to estimate the amount of water that would reach the bottom of the fan if the discharge was spread at the top of the fan. The model comprised a daily water balance component and a finite difference scheme of kinematic wave equation to account for the over land flow. A different model was used for Type 2 fans: the model involved lateral inflow estimation using a US Soil Conservation Curve (SCS) number and a Muskingum Cunge routing model through the Channel (SMUWC, 2001).

*Figure 34: Schematic diagrams of Type 1 and Type 2 fans (SMUWC,2001).*



The Muskingum Cunge model requires information about channel geometry, which was assumed for the rivers of Mkoji, Chimala, Great Ruaha, Kimani, Mlomboji and Mbarali. The governing equations, the channel geometry and other parameters used for the two types of fan type models are not discussed here but can be found in the SMUWC (2001) report, including sensitivity tests. The sub-catchments through which the rivers flow through a definite channel are the Chimala, Great Ruaha, Kimani, Mlomboji and Mbarali sub-catchments. The Kioga, Kimbi and North West sub-catchments have their rivers spreading over the fans.

The sensitivity tests undertaken by the SMUWC project revealed that:

- Loss of water due to evaporation estimated for Type 1 fan model is very high. Although the fans are of a large surface area it seems that the model over-estimates the losses.
- There is no loss or gain of water for Type 2 fan model. This is due to the small size of the fans. Water moves through a definite channel and it takes only a few hours for the water to pass through the fan.

### **6.2.7. Western Flood Plain routing model**

The Western Flood Plain is a seasonal wetland situated in the lower part of the Usangu Plains after the confluences of all the rivers that drain seven of the 11 sub-catchments. This wetland acts as a flood plain in the sense that water flows in the river channel up to the bank-full level. Any flow in excess of the bank-full level causes the river to overflow its banks and flood the area. When water spreads over the flood plain, a substantial amount of water is lost through evaporation. If the inflow into the Western Flood Plain exceeds the bank-full capacity, it is assumed that the excess water will be lost to the flood plain. The SMUWC project recommended using a bank-full capacity of  $110 \text{ m}^3 \cdot \text{s}^{-1}$ .

The Western Flood Plain model was tested by the SMUWC project using the data available for the year 1999. The comparison between simulated and observed flows in 1999 showed that the model performed very well. The bank-full value of  $110 \text{ m}^3 \cdot \text{s}^{-1}$  was also verified. Although the verification showed that most of the water that spreads over the flood plain evaporates, it also revealed that some of it later joins the river system again. The verifications done with the 1999 data showed that the model was fairly accurate. It was therefore decided to include in RUBDA the model as developed by the SMUWC project, and to set a default bank-full value of  $110 \text{ m}^3 \cdot \text{s}^{-1}$ .

### 6.2.8. Eastern Swamp routing model

The inputs to the Eastern Swamp module are the flows into the Great Ruaha River at Nyaluhanga and into the Ndembera River at Madibira. The model assumes that the Eastern Swamp behaves like a reservoir, which has an outlet at NG'irama. This assumption, adopted by the SMUWC modellers, was also used, tested and verified by Kashaigilli (2007). A key assumption of the model is that wetland storage, area and outflow are all a function of water level at the outlet (i.e., at the rock sill at NG'irama). Water elevation-area and water elevation-storage relationships derived during the SMUWC study (SMUWC, 2001d) were fitted with power functions to enable the wetland area and storage to be calculated from water levels at NG'irama. The reservoir is modelled using a Pulse reservoir routing model.

The model computes the water budget using the following equation:

$$Q_{in} = E + Q_{out} - P + S$$

where: S is the change in water stored within the wetland

$Q_{in}$  is the total inflow to the wetland, including contributions from groundwater

$Q_{out}$  is the total outflow from the wetland at the NG'irama exit

P is rainfall falling directly onto the wetland (a function of wetland surface area)

E is evaporation from the wetland (a function of wetland surface area)

Rainfall over the wetland was assumed to be the same as the rainfall over the Usangu Plains, while the Potential Evapotranspiration data were derived from the Dodoma meteorological station. Evapotranspiration from the wetland surface was assumed to be at potential rates in all months.

A rating equation was developed to convert water levels measured at the outlet to discharge (SMUWC 2001b). When the water level is higher than the sill ( $h > 4.30$  m) the equation used is:

$$Q = 5.449 (h - 4.3)^{3.375}$$

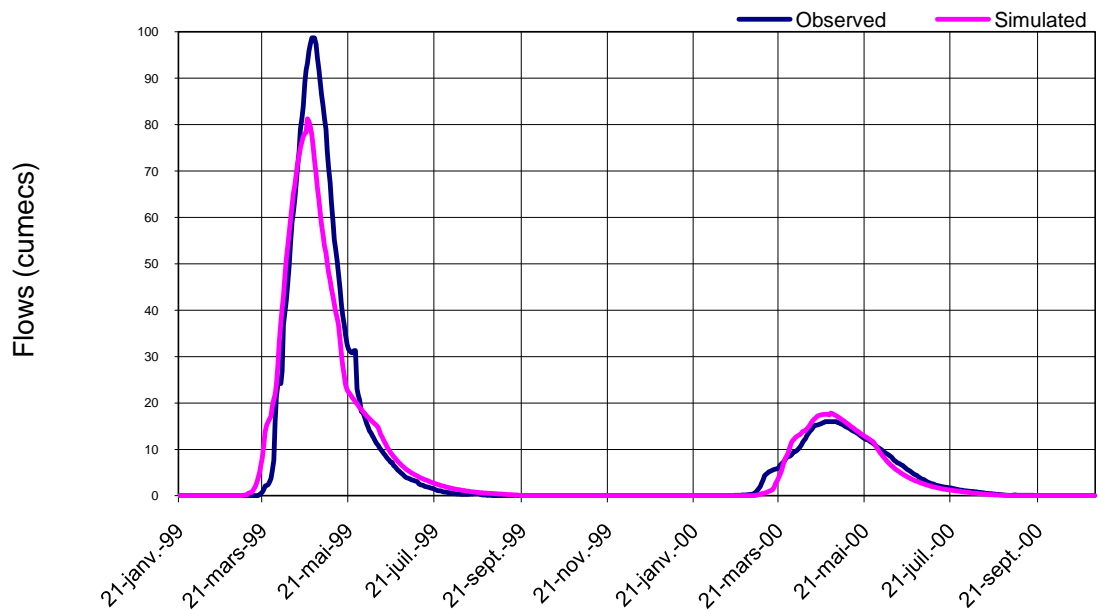
where:  $h$  is the water level measured to a local datum at the outlet

$Q$  is the outflow of the Eastern Wetlands

The rock sill ( $h = 4.30$  m) has an altitude of 1006 m asl. For water levels lower than this, there is no flow from the wetland.

The data available at Nyaluhanga gauging station for the year 1999 enabled the SMUWC modellers to test the validity of the Eastern Swamp routing model without interferences from the upstream sub-catchments. As with the Western Flood Plain, the data recorded in 1999 were used for independent verification of the results of the Usangu Basin Model. The model was calibrated on historical data. The tests run with the Eastern Wetland models for the year 1999 reproduced the outflow very accurately. The observed and simulated outflows of the swamp are shown in Figure 35.

*Figure 35: Graph of the observed and estimated outflows from the swamp.*



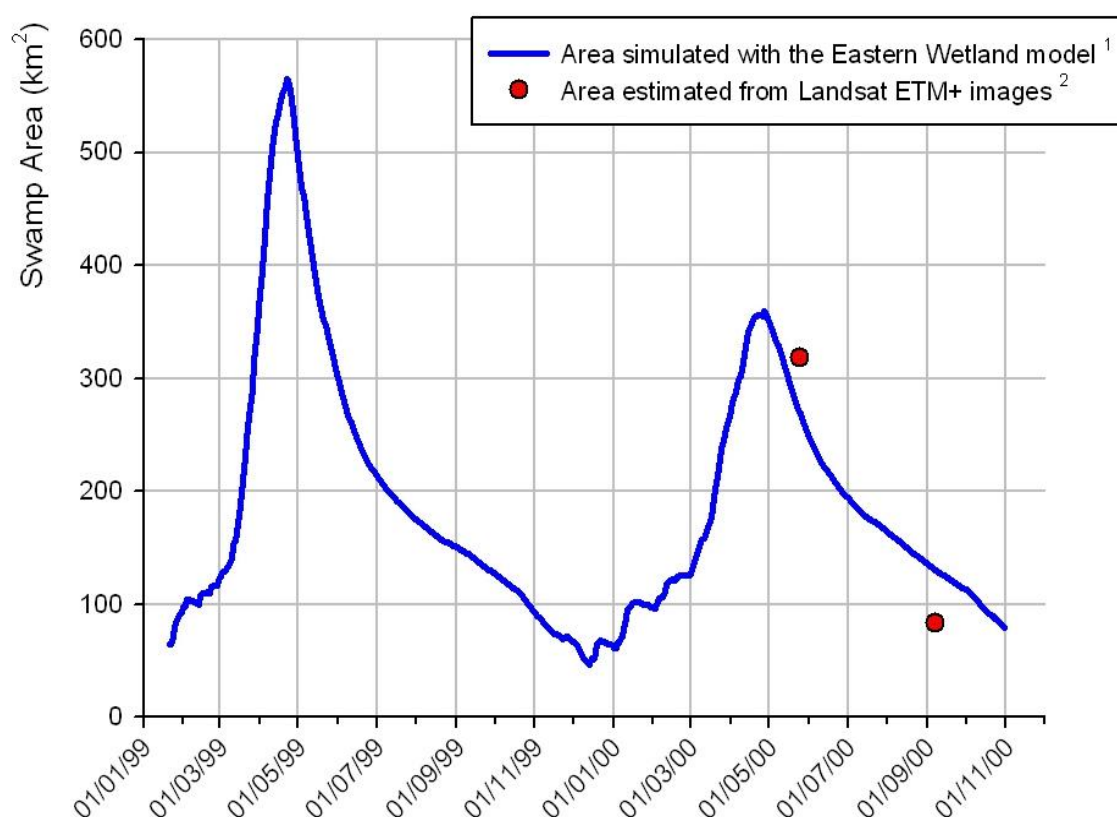


Although the results of the Eastern Wetland model were satisfactory, some reservations were made concerning the storage/discharge relationship because the results were good for the rising limb of the hydrograph and for the peak flows but not for the recession part of the hydrograph. The model also showed limitations for extremely low flows, the equation being only valid when  $h$  is higher than the sill level, which implies that the model does not work properly when flows are lower than  $0.5 \text{ m}^3 \cdot \text{s}^{-1}$ . This reduces greatly the usefulness of the model, because the modelling of such flows is critical for the management of the UGRRC as  $0.5 \text{ m}^3 \cdot \text{s}^{-1}$  is the minimum flow required to maintain the ecosystem in the Ruaha National Park.

To further test the Eastern Wetlands model used in RUBDA, the simulated area of the wetlands was compared to areas estimated by Kashaigilli (2007) using satellite images. The images used are Landsat ETM+ images taken on 26<sup>th</sup> May 2000 and on 7<sup>th</sup> September 2000. The area estimated by Kashaigili (2007) are  $318.10 \text{ km}^2$  and  $82.90 \text{ km}^2$  for the 26<sup>th</sup> May and the 7<sup>th</sup> September respectively. For the same dates, the simulated areas are  $265.4 \text{ km}^2$  and  $130 \text{ km}^2$ . Considering a margin of error linked to the satellite image processing method, it can be considered that the estimated areas and simulated areas are fairly close. The area of the swamp simulated for the years 1999-2000 and the area estimated with satellite images are shown in Figure 36.

Figure 36: Graph of simulated and observed areas of the Eastern Wetlands for 1999/2000

Source of data: Kashaigili (2007)



### 6.2.9. Environmental flow requirements

Environmental flow requirements (EFR) are used in RUBDA v2 to assess the minimum flows required to maintain the ecological status of the Eastern Wetlands and the Ruaha National Park. These EFR can be set by the users on the Eastern Wetlands and Ruaha National Park windows in RUBDA v2, in  $\text{m}^3 \text{s}^{-1}$ , for the dry and wet season. The flows needed for the environment are consumed by the environment sector like for the other water demand sectors. There are water losses in the wetlands and in the Park (percolation and evaporation). However these losses are not accounted for as water uses.

The values of the environmental flow requirements set by default in RUBDA v2 originate from the assessment of the environmental flows for the Great Ruaha River and its wetlands conducted under the RIPARWIN project. The study assessed the dynamics

of the wetlands and concluded that an average dry season inflow of approximately  $7 \text{ m}^3 \text{ s}^{-1}$  is required to enter the wetlands in order to:

- Maintain its ecological status;
- Ensure that a minimum of  $0.5 \text{ m}^3 \cdot \text{s}^{-1}$  flows downstream into the Ruaha National Park

These values are used in RUBDA as the default values of the EFR for the dry season. There are no figures or estimates available of the EFR for the wet season. By default, the wet season EFR is therefore set to nil in RUBDA v2.

### **6.3. Setting up RUBDA v2: The natural, current and vision scenarios**

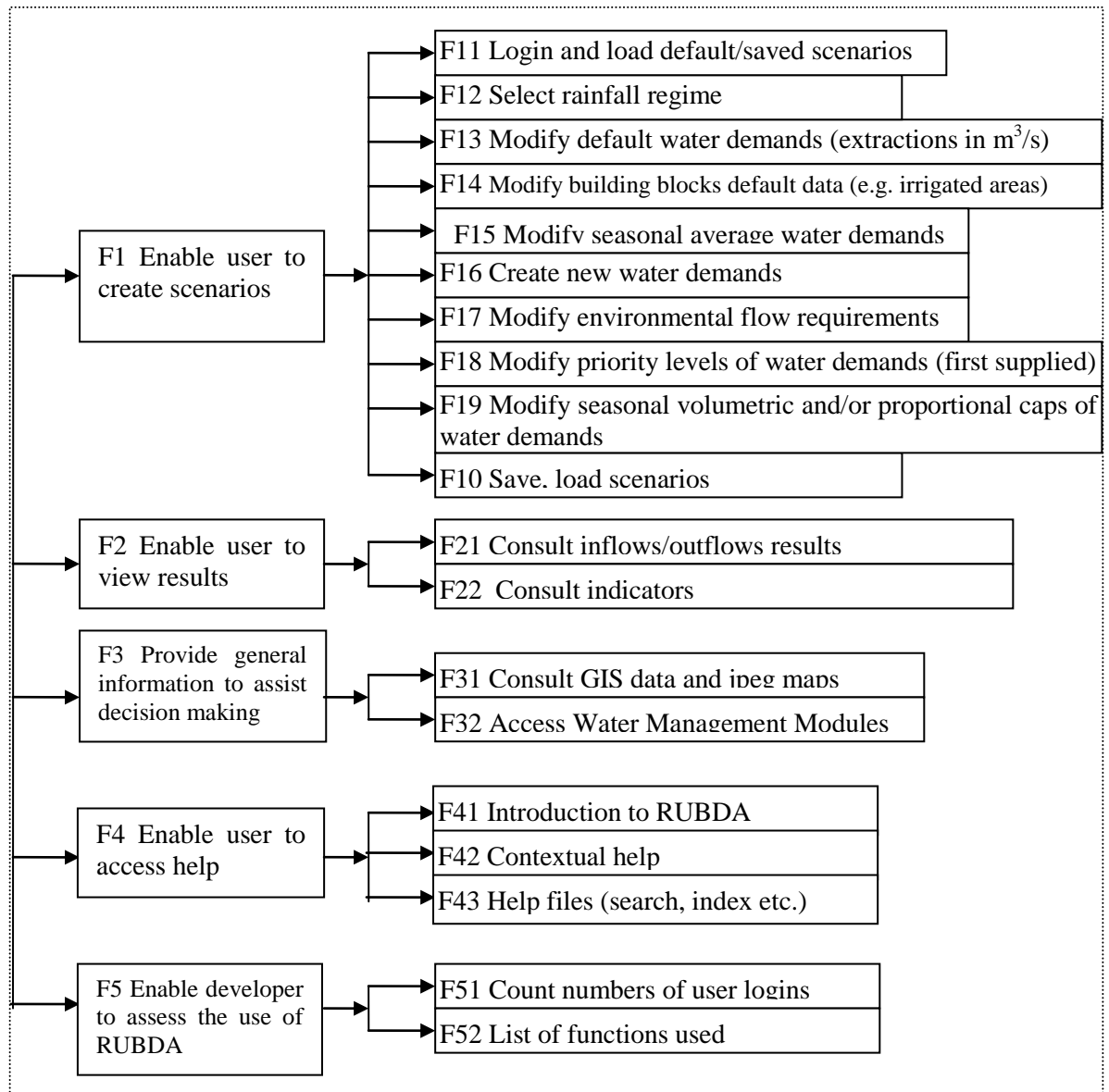
This section provides details about the setting up and running of RUBDA v2 for three different scenarios and pays special attention to the data and water allocation strategies used. The three scenarios are run using data representative of the conditions occurring during a dry year both in the plains and in the higher sub-catchments. The climatic conditions and water uses chosen represent the conditions close to those that occurred during the hydrological year 2002 (November 2001 to October 2002).

The different functions provided by RUBDA to run scenarios are part of the input parameters used by the various hydrological and water demand models used in RUBDA. It is by modifying these parameters that various scenarios can be created. The three scenarios run and presented here to test RUBDA v2 are:

5. A **natural** condition (without human intervention);
6. An **actual** situation (the real situation as it was between 2002 and 2004) and;
7. A “**vision**” scenario (an “ideal” scenario as perceived by the RBWO).

Scenario 1 is used to show the available water in the catchments. Scenario 2 aims to test RUBDA v2 by comparing the results generated with observed data. Finally, the objective of scenario 3 is to assess whether the implementation of the instruments planned by the RBWO will meet the objectives of their vision. The third scenario therefore, runs using those parameters matched as closely as possible to those of the vision of the RBWO.

Figure 37: RUBDAv2 function tree



As illustrated in the functions tree in Figure 37, RUBDA provides a set of functions that enable it to run scenarios (see boxes F12 to F19) and to view results as raw results (F21) or indicators (F22) of the chosen scenarios.

**Box 5: The Rufiji Basin Water Office vision**

Since the Ruaha River first dried up for a few days in the late nineties, the RBWO and other stakeholders have shared a common objective of restoring year round flows in the Ruaha National Park. Having this objective in mind, the RBWO and other stakeholders developed a “water vision” of how water should be distributed in the Upper Great Ruaha River Catchment (UGRRC). One of the main issues put forward in the RBWO vision is that a decrease of water uses in the upstream part of the UGRRC is required. To achieve this, some efforts must be made during the wet season to improve the productivity of water in paddy fields, and during the dry season by limiting water uses. The aim of this decrease is to ensure that the water saved in the higher sub-catchments will reach the Usangu wetlands to restore their natural condition thus enabling a reasonable amount of water to flow downstream to the Ruaha National Park to ensure a minimum contribution from the UGRRC in the dry season to the Mtera Kidatu reservoirs. The RBWO is currently trying to save water wherever possible, but special attention is being given to four of the fifteen sub-catchments, the Kimani, Ndembera, Ruaha and Mbarali rivers. Indeed, these four rivers are the only perennial rivers remaining in the dry season and so the improvement of management practices in these sub-catchments should be sufficient to restore ample river flows to the Usangu wetlands. Nonetheless, the other sub-catchments that dry up during the dry season are not omitted in the RBWO vision: severe water shortages in the dry season, especially in the Mlowo, Gwiri and Mkoji sub-catchments, affect the population located in the lower parts of these sub-catchments.

To meet the objectives set out in the vision detailed above, the RBWO count on a set of “instruments”. These instruments are also described in detail in chapter 3; but the main ones are as follows:

1. All water users are registered and Sub-Catchment Water User Associations (SCWUA) are created or are in the process of being created in the fifteen sub-catchments;
2. The revision of formal water rights to include their transfer from individual users to SCWUAs; which implies important reforms of the legal status of SCWUA to enable their legitimate and effective management of water resources within their sub-catchment;
3. The modernisation of water intakes for irrigation in the sub-catchments;

4. A regulation dam on the Ndembera River to maintain dry season flows to the wetlands;
5. Dry season restrictions in the four perennial sub-catchments implemented by the respective SCWUAs;
6. The upstream/downstream sharing of water within the sub-catchment during the dry season for basic needs.

One of the main instruments that the RBWO plans to use to achieve its vision are the SCWUAs, however, their legitimacy and room for manoeuvre is limited, especially in sub-catchments where customary agreements operating at smaller scales are in place and/or where agreements made are overwhelmingly the decisions taken by the SCWUA committee. Reforms of the legal, financial and technical status of SCWUAs are planned in the forthcoming Water Resources Bill which should enable their integration into existing institutional frameworks.

To run the three scenarios, tests were run using the scenario loader (saving and opening) functionality of RUBDA v2. The scenarios are saved as text files and are linked to the user's account. After logging-in the user is prompted to either create a new scenario or to load an existing one. In our case, the three scenarios were saved and can be loaded using the scenario loader window as shown in Figure 38.

*Figure 38: Screen shot of the scenario loader window*



In Scenario 1, **natural** conditions are simulated, thus water uses are set to zero for all water use sectors. From this assessment, one can estimate the total amount of water available at the various scales of the UGRRC. The initial outflow (on the first day of the hydrological year) from the Eastern Wetlands was set at  $3 \text{ m}^3 \text{ s}^{-1}$ , because this corresponds to the average outflow for November (Kashaigili, 2007). The water allocation strategy module is used here to set the maximum water abstraction rates of all the sectors to zero. The scenario thus shows what would be the situation if there was no water abstracted, diverted or used by humans in the basin.

In Scenario 2, **current** condition, the water demand set for a dry year is used and there are no restrictions applied. The water demands of the different sectors are those set by default in RUBDA v2, and are presented in section 6.2.4. Although in 2002 the RBWO had started to impose restrictions on dry season water abstraction, especially in the Mbarali sub-catchment, no restrictions on water abstractions were set when running scenario 2.

The parameters used in Scenario 3, the **vision** scenario, reflect the objectives set by the water vision of the RBWO. The sub-catchments have specific objectives that all serve the main one: to restore year round flows in the RNP. To achieve this goal, a minimum of  $7 \text{ m}^3 \cdot \text{s}^{-1}$  of total inflow (the sum of all the flows generated in the 11 sub-catchments) has to feed into the Eastern Wetlands during the dry season. The RBWO relies mainly on four of the eleven sub-catchments to reach its fixed objective. These four sub-catchments are the Ndembera, Great Ruaha, Kimani and Mbarali Rivers. The objectives for the four sub-catchments are different and linked to the characteristics of each sub-catchment. Each river needs to be tackled separately taking into account the nature of the water uses. The parameters used in each of the sub-catchments for the modelling of the vision scenario are described in the following paragraphs.

### 6.3.1. Kimani Sub-Catchment Parameters

The Kimani sub-catchment has an existing SCWUA in place; the MAMREMA WUA. The RBWO was planning to empower the MAMREMA association to implement the

water allocation strategies and achieve the objectives set out in its vision. In Scenario 3, the assumption is made that the empowered MAMRENA association would have the capacity to implement the water allocation strategies set by the RBWO. The characteristics of the Kimani sub-catchment and the capacity of the MAMRENA association to implement the RBWO's plans are not discussed here. The RBWO was planning to get the SCWUA to stop all water abstractions linked to dry season irrigation going on in the Kimani sub-catchment. The dry season irrigated area is therefore set to zero for the Kimani sub-catchment.

### **6.3.2. Mbarali Sub-Catchment Parameters**

The Mbarali sub-catchment is of particular interest because of the presence of an important irrigation scheme, the Mbarali rice scheme, and because the RBWO has initiated a canal regulation programme during the dry season. The amount of water being abstracted by the Mbarali rice farms has been closely regulated and monitored by the RBWO since 2004. This has had some impact on the river flows downstream of the water intakes. The coefficient of abstraction for the Mbarali River dropped from 52% in 2003 to only 17% in 2004. Farms were restricted from abstracting water during the night. This was clearly reflected in the downstream gauge readings taken in the morning. On top of this, there was no early transplanting of paddy during 2004/05 (in November) because of the delay in allowing the farms to be leased to individuals for paddy cultivation. As a result, the average dry season abstractions from Mbarali River dropped from  $1.454 \text{ m}^3 \cdot \text{s}^{-1}$  (52.4% of the river flow) in 2003 to  $0.577 \text{ m}^3 \cdot \text{s}^{-1}$  (17.3% of the river flow) in 2004 (RIPARWIN, 2006) .

To reflect the canal regulation programme that is being progressively implemented on the Mbarali River, the dry season irrigated area for the Mbarali sub-catchment is set at 80 ha in Scenario 3. This is approximately one third of the irrigated area used for the current scenario.



### **6.3.3. Great Ruaha Sub-Catchment Parameters**

The Great Ruaha is one of the rivers from which the RBWO intends to reduce water abstractions during the wet season and stop water abstractions altogether during the dry season. The dry season irrigated area for this sub-catchment is thus set to zero in Scenario 3.

### **6.3.4. Ndembera Sub-Catchment Parameters**

The Ndembera sub-catchment is given special attention in this study because: i) the Ndembera River is perennial; ii) it has an important rice irrigation scheme, the Madibira rice farm; and iii) the RBWO plans to give this sub-catchment an important role in restoring downstream flows through the construction of a regulation dam. As stated by Kashaigilli et al (2005; 2007) a number of large-scale projects have been proposed to restore perennial flows to the Great Ruaha, “amongst them, the concept of placing a regulatory dam upstream of the wetlands has been acknowledged by many to act as a possible solution”. The RBWO envisage building a regulatory dam on the Ndembera River to provide water downstream during the dry season to maintain the Eastern Wetlands and to provide water to the Ruaha National Park (Mwaruvanda, 2007). The idea of building a dam on the Ndembera River was put forward long before it was envisaged by the RBWO. It was first initiated as part of the Kapunga/Madibira Rice Project (Halcrow, 1985). The dam was at that time envisaged to support irrigated rice in the Ndembera sub-catchment. Research conducted in 2007 about the dam initiatives led to the production of a dissertation by Jones (2008). Because of their importance regarding the present work, Jones’s research results are carefully presented and discussed in the following paragraphs.

#### ***A dam for irrigation (Synthesised from Jones, 2008)***

The Madibira Rice Project consisted of two separate phases. The implementation of Phase I of the Madibira Rice Scheme started in 1998 and was funded by a loan from the African Development Bank. The scheme consisted of 3000 ha of cultivated rice paddy, run under smallholder management whereby farmers received 1 ha of arable land and

joined the Madibira Agricultural Marketing Cooperative Society (MAMCOS). Rice is cultivated using supplementary irrigation with water extractions from the nearby Ndembera River. Phase II of the project has not yet been implemented; this phase includes an increase in the area under cultivation to reach 8000 ha of wet season paddy and 6000 ha of dry season maize, thus requiring substantial water supplies (Jones 2008). Halcrow (1985) suggests that a storage reservoir located at Lugoda (55 km upstream of Madibira) would be necessary to meet the irrigation water demand. The dam would store wet season flows, releasing water into the Ndembera River to supplement dry weather flows for irrigation. Halcrow (1985) concludes that an earth-filled dam with a storage capacity of  $210 \text{ Mm}^3$  would be needed. Halcrow (1985) states that the water released by the Lugoda dam would also benefit downstream uses; however this statement is questionable because the water releases would be dictated by the irrigation water demand.

### ***A regulatory dam for the environment***

The RBWO identified the Lugoda site as appropriate for the building of a regulatory dam on the basis of feasibility studies undertaken by the Madibira Rice Project. However the RBWO insisted that if the dam was to be built it would “function primarily as a means of regulating environmental flows, ensuring effective perennial flow, rather than [for] its intended purpose of construction, [for] providing irrigation for the downstream Madibira rice scheme” (Jones, 2008, p.17). The RBWO insisted that they would not give the authorisations needed by the Madibira Rice Project to build the dam, unless the dam was to have the capacity to accommodate both the water demand of the environment and irrigation. In this case, the RBWO was ready to share the water and to manage the dam in a multipurpose manner (Mwaruvanda, 2007). However the chances of having a multipurpose dam were reduced by the fact that the RBWO envisaged the building of a smaller dam of about  $50 \text{ Mm}^3$  storage capacity, to reduce the dam’s environmental impact. The dam would have to release around  $10 \text{ m}^3.\text{s}^{-1}$  of water during the dry season, and dry season irrigation would have to be stopped across the entire Ndembera sub-catchment. These figures were, at the time of the study, “guessed” by the RBWO because the RBWO was still waiting to launch a study funded by the World Bank to explore the feasibility of building the dam. A dry season environmental flow of  $10 \text{ m}^3.\text{s}^{-1}$  for the Ndembera River is much higher than the  $7 \text{ m}^3.\text{s}^{-1}$  of environmental

flow estimated by Kashaigili (2007), which corresponds to the minimum dry season flows required to maintain the wetlands and minimum flows of  $0.5 \text{ m}^3.\text{s}^{-1}$  in the Ruaha National Park. Kashiagili's (2007) environmental flows actually correspond to the total inflows required from all the 11 sub-catchments. For instance, the dry season flows generated by the Ndembera sub-catchment between 1998 and 2003, after irrigation intakes, is about  $0.7 \text{ m}^3.\text{s}^{-1}$ , whereas the flows generated by the sub-catchment before intakes is on average  $1.38 \text{ m}^3.\text{s}^{-1}$  which represents about 15 % of the dry season flows generated by the four perennial sub-catchments before intakes. Hoping to get  $10 \text{ m}^3.\text{s}^{-1}$  from the Ndembera sub-catchment, means that the RBWO intends to get much more than the  $7 \text{ m}^3.\text{s}^{-1}$ . Jones (2008 p 27) concludes that a  $50 \text{ Mm}^3$  dam is not an appropriate solution:

*“A small regulation dam ( $50 \text{ Mm}^3$  storage capacity) would be of great convenience,[ if] (in) that full capacity could be achieved in a matter of 47 days (commencing at start of the wet season). A reduced storage capacity would also ensure that only a small portion of land would be submerged, significantly reducing its environmental impact. However, simulation results demonstrate that under a  $50 \text{ M}$  cubic meter capacity, a discharge of  $10 \text{ m}^3.\text{s}^{-1}$  could only be maintained for a maximum of 58 days, from full capacity to dead storage. This would clearly not be sufficient to satisfy the dam's given purpose, given the dry season runs for period of 7 months. It is therefore recommended that a significantly larger storage capacity be selected.”*

It is interesting to note that the Madibira Rice Project stated that the irrigation dam would benefit downstream users and that the RBWO envisaged that – in case the storage capacity allowed it – the regulatory dam could provide water for irrigation. Because the two “sectors” displayed the willingness to share the water stored in the dam with other water demands, an interesting question that arises is whether a  $210 \text{ Mm}^3$  dam would have the capacity to meet both the demands of the irrigation and of the environment. Jones (2008) attempted to answer this question by running different scenarios using various irrigation areas and environmental water demands. The dam simulation model used by Jones (2008) was initially developed in 2004 to be included in RUBDA; however at that time the inclusion of a dam model in RUBDA was not identified as a priority. Later, the willingness of the RBWO to build a dam increased but

because of time constraints the dam model was never finished nor included in RUBDA. The dam model parameters were updated in 2007 using the characteristics of the Lugoda Dam provided by Halcrow (1985). Jones (2008) ran simulations using the dam model, manually replacing the Ndembera sub-catchment inflow files in RUBDA v2 with those of the dam simulation outflows. Because the model is a bit simplistic it was necessary to test it. Some simulations were done using dam initial storage, rainfall regimes and evaporation data similar to those run by Halcrow (1985). The results generated by the dam model were substantially similar to those of Halcrow (1985); so it was concluded that the model was appropriate for the research done by Jones (2008).

Jones (2008) formulated and ran five different scenarios:

1. **Scenario Nil: No dam simulation** and no water abstracted. Natural flow conditions;
2. **Scenario A: Regulatory dam**, environmental flow releases of  $10 \text{ m}^3\text{s}^{-1}$ , commenced at half storage capacity. No increases of water abstractions allowed, whilst the Madibira Rice Scheme retains the current area under rice cultivation;
3. **Scenario B: Multipurpose dam**, irrigation expansion during wet season (8000 ha) but releasing  $10 \text{ m}^3\text{s}^{-1}$  of environmental flows. Dry season irrigation is not permitted in compliance with the existing dry season water restrictions applied by the RBWO in the Ndembera sub-catchment;
4. **Scenario C: Multipurpose dam**, irrigation expansion during wet season (8000 ha), but water releases from the dam of  $13 \text{ m}^3\text{s}^{-1}$  as recommended by Halcrow (1985) to supply irrigation. No dry season irrigation;
5. **Scenario D: Irrigation dam**, full expansion during wet season (8000 ha) and dry season (6000 ha) with  $13 \text{ m}^3\text{s}^{-1}$  of water released from the dam.

Table 25: Scenario, dam and agriculture parameters, modified from Jones (2008)

	Scenario Nil	Scenario A	Scenario B	Scenario C	Scenario D
Dam	No	Yes	Yes	Yes	Yes
Dam Outflow ( $\text{m}^3 \cdot \text{s}^{-1}$ )	X	10	10	13	13
Wet Season Rice cultivation area (ha)	4000	4000	8000	8000	8000
Dry Season irrigation (ha)	0	0	0	0	6000

#### Results and evaluation of Jones (2008) scenarios:

The five scenarios were evaluated by their ability to satisfy the irrigation water demand and to ensure that the required environmental flows are met. Although the RBWO is willing to get as much water as possible from the Ndembera sub-catchment, Jones (2008) considered that the minimum environmental flows required to enter the wetlands was  $7 \text{ m}^3 \text{ s}^{-1}$  (from the 11 sub-catchments); and not  $10 \text{ m}^3 \text{ s}^{-1}$  solely from the Ndembera sub-catchment as mentioned by the RBWO which Jones considered unrealistic considering the existing pressure on water resources. Scenario Nil certified that changes to the current water management systems were indeed needed in order to satisfy downstream environment flows, given that the minimum required flow of  $7 \text{ m}^3 \text{ s}^{-1}$  entering the Ihefu were achieved for only 167 days per annum. The scenarios run by Jones (2008) reveal that a dam of  $216 \text{ Mm}^3$  storage capacity is viable and could maintain an outflow of  $10 \text{ m}^3 \cdot \text{s}^{-1}$  for the environment throughout the year. Furthermore, it shows that the same dam could be used as a multipurpose dam satisfying both the irrigation and the Environmental Flow Requirement; if the irrigated area is maintained as it is during the wet season (4000 ha) but is nil during the dry season. If phase II of the Madibira Project is achieved (8000 ha) but without dry season irrigation occurring, both the irrigation water demand and the environmental flow requirements would only be partially met. Jones (2008) shows that building a dam for irrigation when Phase II is implemented and dry season irrigation is allowed would drastically reduce the amount of water flowing downstream; in this case not meeting the environmental flows that are required to maintain the wetlands.

Figure 39: Screenshot of RUBDAv2 simulated Ndembera flows under Scenario A, from Jones (2008)

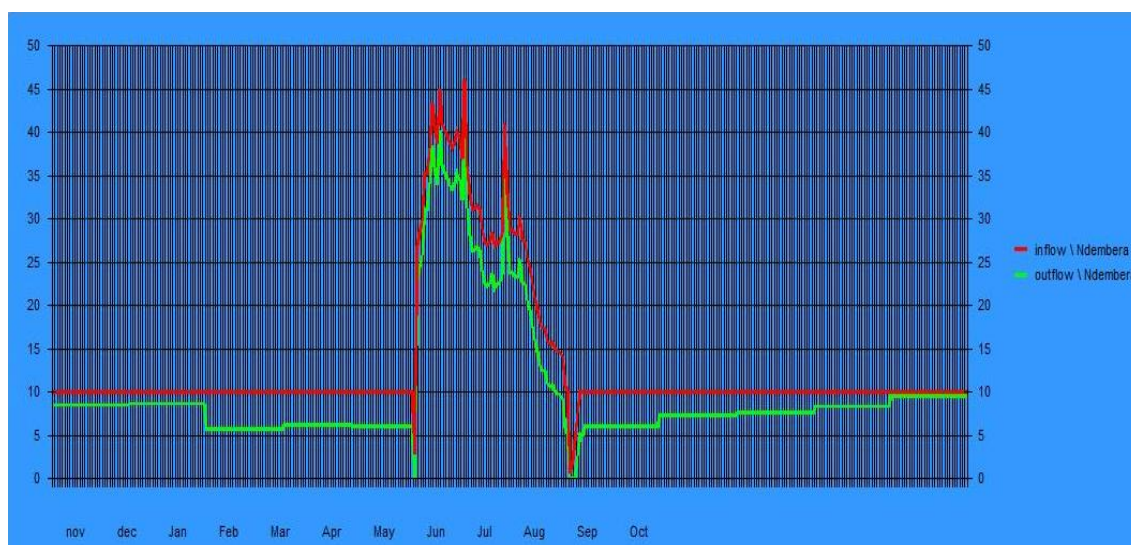


Table 26: The number of days minimum required flows in the Eastern Wetlands are met under each scenario

	Number of days Minimum Required Flows met			No. of days Minimum Requirement not met
	Wet Season (151 days)	Dry Season (214 days)	Annual (365 days)	Annual
Scenario Nil	134	33	167	<b>198</b>
Scenario A	149	188	337	<b>28</b>
Scenario B	96	116	212	<b>153</b>
Scenario C	133	166	299	<b>66</b>
Scenario D	94	116	210	<b>155</b>

Jones (2008: 36) concludes that the “scenarios A and C are recommended as the best solutions to achieving effective sustainable water resource management in the Usangu as the two scenarios only fail to achieve minimum required inflow into the wetlands on 28 and 66 days respectively. Importantly, it is noted that whilst inflow does fall below the required minimum level on a few occasions, it does so only by slight margin, compared with the results generated for the other scenarios.”

Another impact identified by Jones (2008) is that the flows generated by the Ndembera River under Scenario C (multipurpose dam with extended irrigation during wet season) would remain relatively stable compared to the actual situation. Because the Ndembera

River enters the wetlands in its downstream part, Jones (2008) indicates that the flows generated under Scenario C could create a smaller but permanent wetland. This situation is described as follows by Kashaigili (2005): a smaller but stabilized wetland would reduce the water losses due to evaporation, decrease the environmental flows required to maintain the wetlands and reduce the inflow required to generate the same outflow to the downstream Great Ruaha River. And although it would differ from the natural state of the Eastern Wetlands it may be of significant benefit to the downstream hydrology. Kashaigili (2005) suggests that for a 4000 ha “managed” wetland an inflow of 4 to 6 m<sup>3</sup>s<sup>-1</sup> would be sufficient to generate an outflow of 0.5 m<sup>3</sup>s<sup>-1</sup>. If a smaller wetland was considered as acceptable by the environmental “sector” and by the RBWO, the year round inflows generated under Scenario C could therefore present itself as a viable option regarding allocation of water resources.

Nevertheless, Jones (2008: 40) warns that “increasing the available water resource, through increased storage, may be hindered in its success, given the extent to which unmonitored and widely unregulated illegal abstractions occurs in the Usangu. If no effective methods are taken to assess and resolve such widespread profusion, the dam’s construction may simply facilitate further proliferation of illicit abstractions.”

The simulations run by Jones (2008) only consider changes occurring on the Ndembera sub-catchment and not on the other sub-catchments, thus further studies are required to assess whether 8000 ha of paddy fields during the wet season in the Ndembera sub-catchment would be viable if restrictions are applied to other sub-catchments. Indeed, an increase in the irrigated area in the Ndembera sub-catchment could be compensated by a decrease in water uses in other sub-catchments. Nevertheless, the RBWO does not consider an increase in the irrigated area as a priority in the UGRRC. Currently the RBWO’s efforts are aimed towards limiting the irrigation water demand; in this context, an expansion of the Madibira Irrigation Scheme seems unrealistic.

Ndembera sub-catchment parameters for Scenario 3:

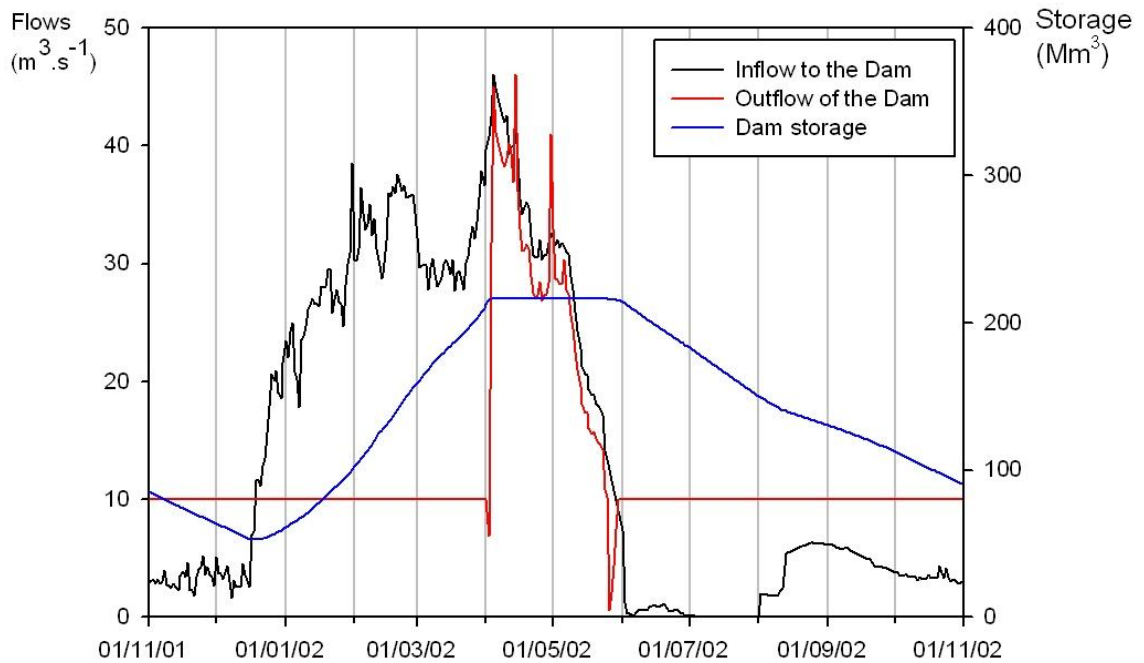
Considering the results of the simulations run by Jones (2008), Scenario 3 (the vision) uses the following parameters:

- A 216 Mm<sup>3</sup> storage capacity multipurpose dam;

- $10 \text{ m}^3\text{s}^{-1}$  outflow from the dam for irrigation (wet season) and environmental flow requirements;
- 4000 ha of irrigated paddy fields during the wet season;
- No dry season irrigation.

The dam model is run prior to the RUBDA v2. The outflows of the dam as generated by the dam model (shown in Figure 40) are then used as inflows to the Ndembera sub-catchment in RUBDA v2. This is done by replacing the inflows text files in the data folder of RUBDA v2.

*Figure 40: Graph of the dam storage and of the Ndembera River flows upstream and downstream of the dam*



#### **6.4. Results and evaluation of the scenarios**

This section presents a summary of the key results obtained when running the scenarios presented in the previous section: the natural, actual/current and vision scenarios. Detailed results of the three scenarios are provided in Appendix B. Before presenting the results generated by RUBDA for the scenarios, a short section describes how results and indicators are displayed in RUBDA. To follow the structure of RUBDA and fit with the way the managers from the RBWO perceive and manage or would like to manage



(their vision) water, the results are first given at the sub-catchment level and second for the downstream parts of the UGRRC. The natural condition scenario was run to show what the hydrology of the UGRRC would have been without any human water abstractions; and only key results are used here (in Section 6.4.3). Detailed results of the Natural condition scenario are presented in Appendix B. All the water demands were set to zero, so the river flows generated by the models represent the water that could be available in the various sub-catchments and in the downstream parts of the UGRRC.

#### **6.4.1. Display of results in RUBDAv2**

Results follow the logic adopted to enter water demands, rainfall and water allocation strategies. They can be displayed in three different formats. The user can choose the format by using buttons on the toolbar or by using menus. The first format is a **graph** (Figure 41) which shows the daily inflows and outflows of the sub-catchment or of the hydrological unit (Floodplain, Eastern Wetlands and Ruaha National Park).

The second is a “**data summary**” (Figure 42) which provides in a tabular format the monthly averages of inflows and outflows as well as the annual averages.

The third format is a set of **indicators** (Figure 43, Figure 44) presented as graphs which display the inflow and water demands specified by the user (for the sub-catchments) or the inflow and the environmental flow requirements (for the Wetlands and the Ruaha National Park), as well as some of the indicators (defined during the design phase) relevant to the hydrological unit concerned.

The graphs are generated using the Visual Basic MSChart and MSflexgrid tools, (which come standard on all Microsoft Office equipped machines), in order to reduce compatibility problems. It is possible to zoom in on the graphs, and to get the daily flow values by double clicking on any point on the curves (Figure 41).

Figure 41: Screen shot of a zoomed graph window showing the inflows and outflows of the Eastern Wetland.

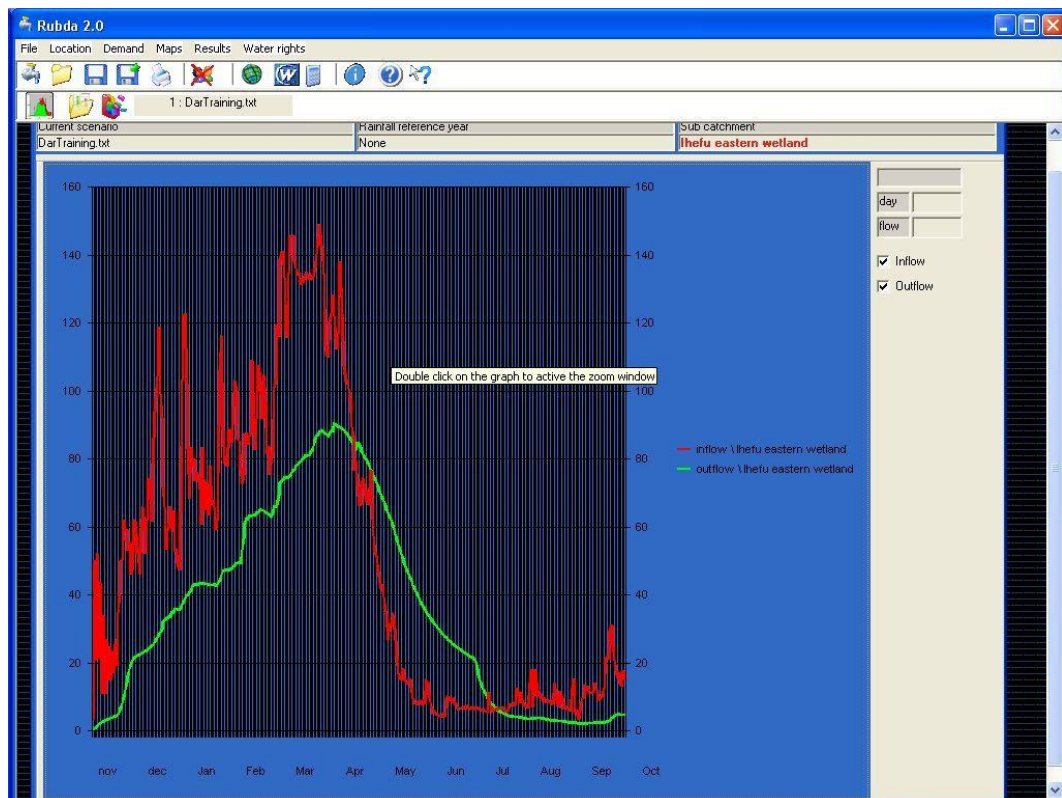
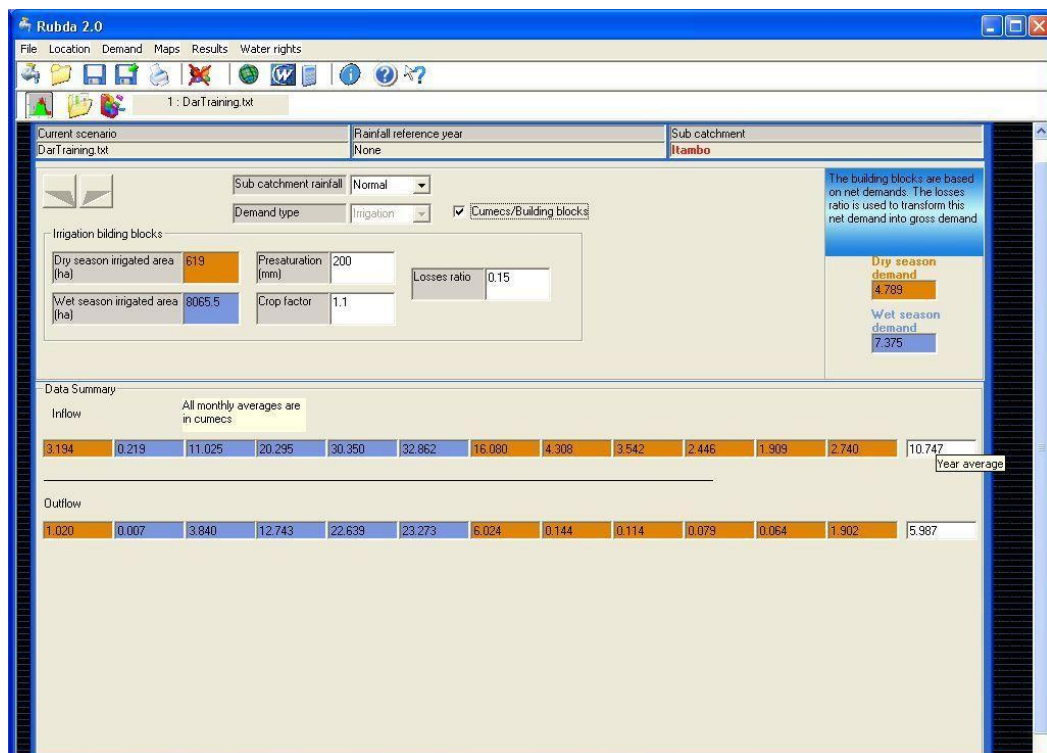


Figure 42: Screen shot of a data summary results window showing the monthly and annual averages of the Itambo Sub-Catchment inflows and outflows



The estimated indicators differ between the sub-catchments and the downstream hydrological units. For sub-catchments these indicators are the number of days the water demand is met, the number of days the volumetric or proportional caps were used (in our case there were no allocation rules defined), and the number of days the demand is totally or partially met. All the indicators are estimated for the dry and wet season separately. For the Western Floodplain, the indicators provided are the number of days the inflows are above the bank-full value (when the river floods) for the dry season and wet season. For the Eastern Wetland and Ruaha National Park the indicators provided are the number of days the environmental flow requirements are met during the dry and wet seasons.

Figure 43 shows a screenshot of the indicator results window for the Itambo Sub-Catchment. The window is divided into four parts, each showing different information:

- The upper left part contains the parameters used to generate the water demand, in this case the irrigation parameters set using the building blocks
- The upper right part shows the average dry season and wet season water demand in  $\text{m}^3 \text{s}^{-1}$ , estimated using the data entered by the user
- The lower left part is a graph showing the available water in the river and the irrigation water demand. The available water takes into account water abstracted by higher priority demands that were therefore supplied first
- The lower right part shows the allocation strategy defined by the user (here there are none), and the indicators.

Figure 43: Screen shot of the indicators window for the Itambo Sub-Catchment

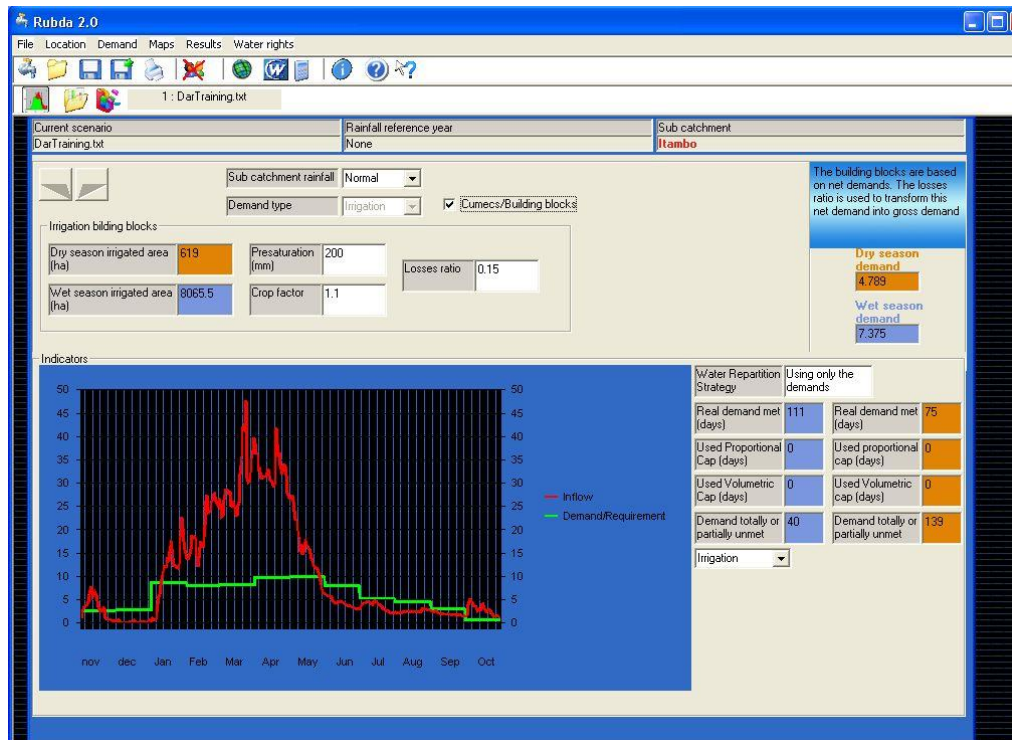
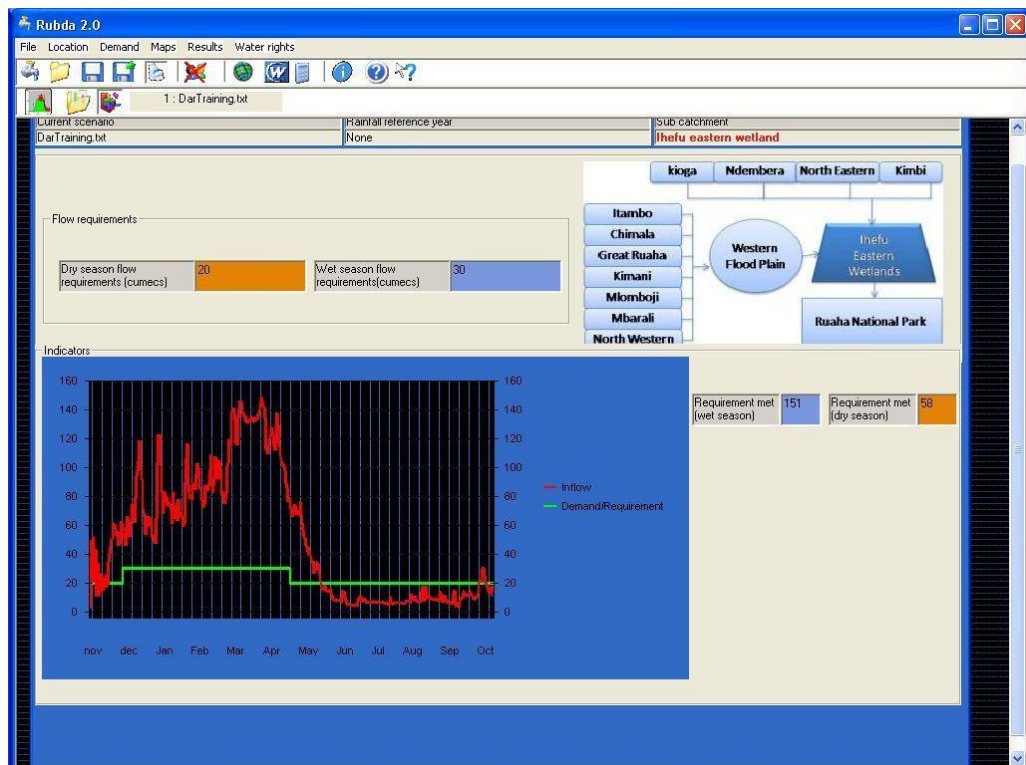


Figure 44: Screen shot of the indicators window for the Eastern Wetlands



Indicators are calculated using the scenario parameters (water demands, environmental flow requirements) combined with the hydrological results generated by the model. These indicators were defined and included in RUBDA to provide results that are more relevant for end-users than simply river flows in  $\text{m}^3 \text{s}^{-1}$ .

#### 6.4.2. Scenario 2: The current condition

*This scenario was run by the developers, using the demand data for the years 2002/2003, to test RUBDA. The input data used for this scenario are the data set by default in RUBDA v2. The results generated were presented during the training sessions (to test RUBDA), and the participants were satisfied both by the input and output data, which they perceived to be close to reality. The graphs and tables presented in this section (Figure 45 to Figure 47; Table 27 and*

*Table 28) were generated using the output text files generated by the hydrological models; and have been extracted from RUBDA to ease their display.*

Figure 45: Scenario 2, Mbarali SC inflow and monthly averages of irrigation demand.

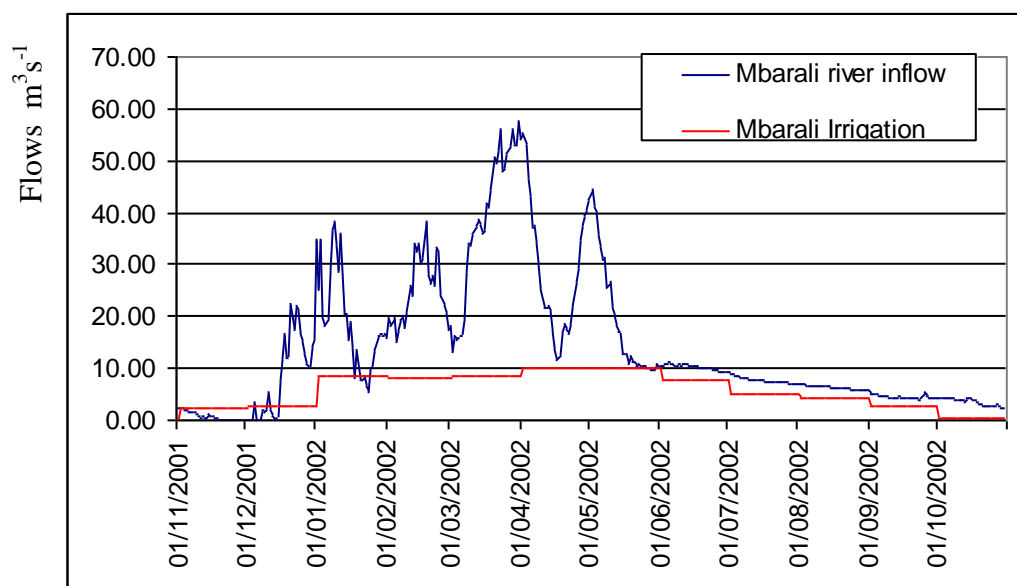


Figure 46: Scenario 2, Ndembera SC inflow and monthly averages of irrigation demand.

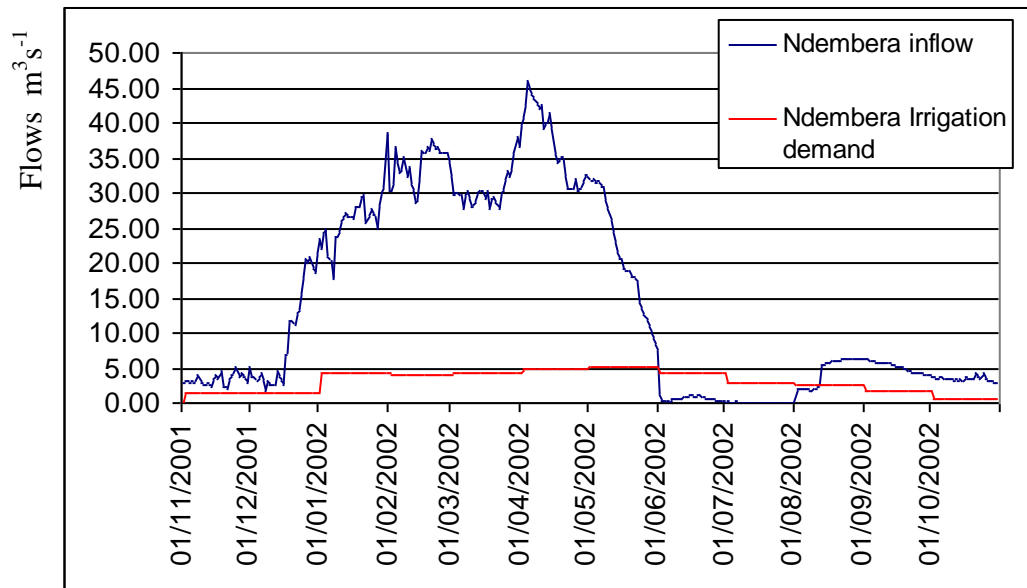
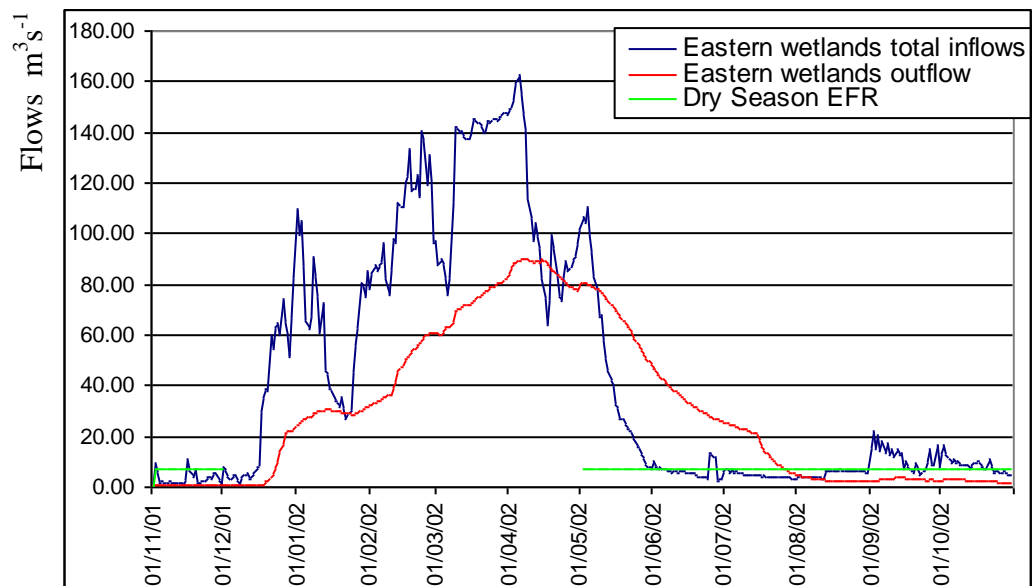


Figure 47: Scenario 2, dry season Environmental Flow Requirements and Inflows and outflows of the Eastern wetlands.



The selected graphs (Figure 45 to Figure 47), which use data from 2002/2003, show the extent of water shortages in the UGGRC. Most of the water demands, apart from domestic uses and brick making, were actually not supplied during the dry season in the various sub-catchments. Furthermore, the Eastern Wetlands did not receive the environmental flow requirements (where EFR was estimated to be  $7 \text{ m}^3 \text{s}^{-1}$ ) that were

necessary to maintain its natural condition and to ensure downstream flows to the Ruaha National Park ( $0.5 \text{ m}^3 \text{ s}^{-1}$ ).

*Table 27: Scenario 2, sub-catchment flows before and after water abstractions, irrigation water demand and number of days the demand is not satisfied (totally or partially).*

SC	Wet season average flows before abstractions ( $\text{m}^3 \cdot \text{s}^{-1}$ )	Dry season average flows after abstractions ( $\text{m}^3 \cdot \text{s}^{-1}$ )	Wet season average irrigation demand ( $\text{m}^3 \cdot \text{s}^{-1}$ )	Dry season average irrigation demand ( $\text{m}^3 \cdot \text{s}^{-1}$ )	Wet season Number of days the irrigation demand is not met	Dry season Number of days the irrigation demand is not met
Itambo	14.45	3.66	4.12	3.85	37	174
Chimala	8.05	1.63	1.00	0.83	14	28
Great Ruaha	28.15	4.15	3.31	1.92	17	41
Kimani	11.24	2.25	2.14	1.25	16	30
Mlomboji	11.24	2.25	0.02	0.00	0	0
Mbarali	24.00	7.56	7.52	4.59	18	30
Kioga	25.77	5.33	3.57	2.19	5	16
Ndembera	27.41	5.50	3.78	2.62	0	72
North Eastern	4.17	0.86	0.00	0.00	1	3
Kimbi	22.46	2.03	0.02	0.01	6	20
North Western	31.31	5.06	0.25	0.14	1	3
Total	210.78	42.22	25.72	17.40	115.00	417.00

*Table 28: Scenario 2, inflows and outflows of the Eastern wetlands and flows into the Ruaha National Park.*

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
<b>Total inflow to eastern wetlands (<math>\text{m}^3 \text{ s}^{-1}</math>)</b>	3.3	29.7	60.7	106.2	129.0	105.7	46.8	6.3	4.7	5.3	11.9	8.5
<b>Outflow of the eastern wetlands (<math>\text{m}^3 \text{ s}^{-1}</math>)</b>	0.6	6.9	31.1	50.3	76.5	89.1	69.4	34.7	16.4	2.9	3.4	2.6
<b>Inflow RNP (<math>\text{m}^3 \text{ s}^{-1}</math>)</b>	0.5	5.7	27.8	44.6	69	81.7	64.8	32.9	15.5	2.7	2.9	2.2

The competition occurring in the UGRRC between the downstream “users”, namely the wetlands and the Ruaha National Park, and the upstream users (mainly irrigation) appears challenging to solve because the upstream users do not even get the flows they expect during certain critical periods in the dry season and even at the beginning of the wet season. The river flows entering the RNP, presented in

Table 28, are monthly averages and thus do not show the days when the Ruaha River dries up (these are presented in Table 31). Local river flow variations during these months affect the averages, as does the way the Eastern Wetlands are modelled and

calibrated in RUBDA. It appears that the Eastern Wetlands Model tends to overestimate flows at the outlet of the Eastern Wetlands when they are very low.

### 6.4.3. Scenario 3: The vision condition

The vision scenario was simulated using the 2002/2003 water demand (as for the current scenario described above) but using allocation rules that match the restrictions envisaged by the RBWO (described in detail in Box 5). Running this scenario had two aims; first to test whether the measures envisaged by the RBWO would have the intended impact – to restore downstream flows – and second, to ensure that RUBDA can provide the type of answers needed by the RBWO managers.

Results show that the restrictions applied to the irrigation demand would have significant impacts upon the water abstracted, such as forbidding dry season irrigation in Kimani and Ruaha sub-catchments and reducing the irrigated area in the sub-catchments by a third (80 ha of irrigated area). However, results also show that even when the number of days the irrigation demand is not met is reduced, there would still be months (especially November) during which the supply would be insufficient (see Figure 48 and Table 30).

Figure 48: Scenario 3, Mbarali Sub-Catchment inflows and monthly averages of irrigation demand.

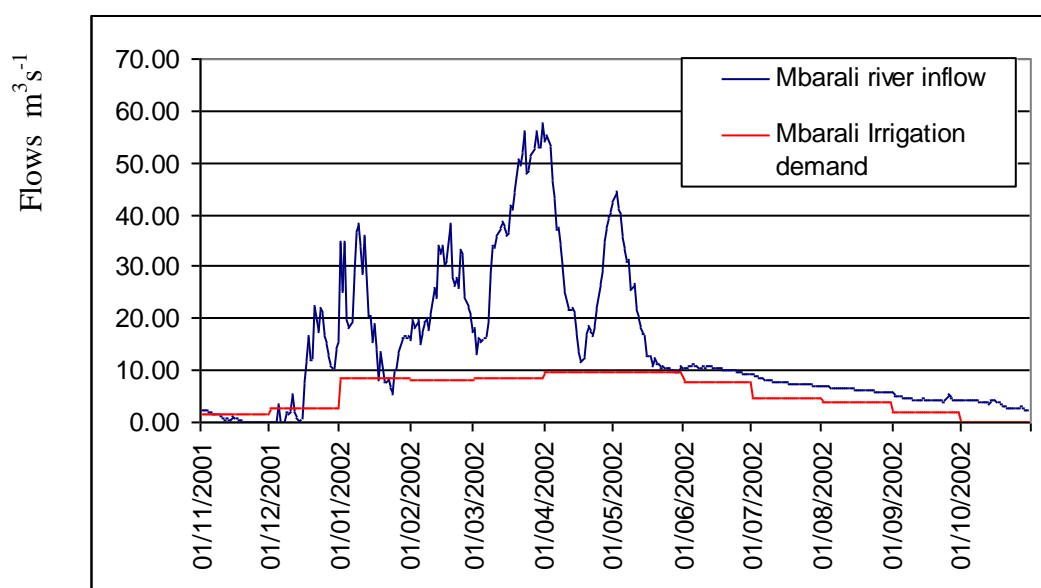
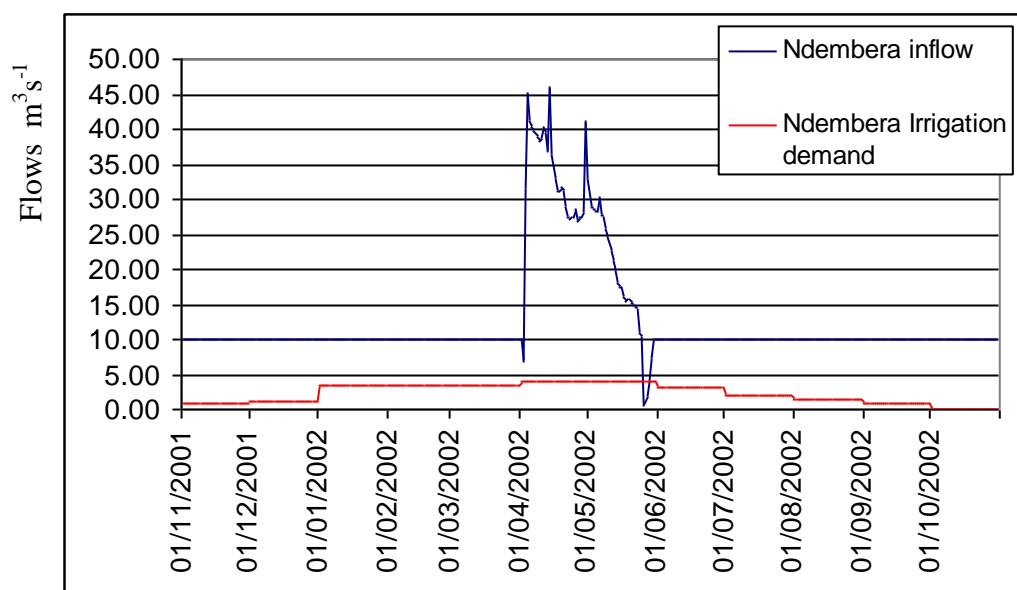




Figure 49: Scenario 3, Ndembera Sub-Catchment inflows and monthly averages of irrigation demand.



The results also give some idea of what the impact of building a 216 Mm<sup>3</sup> storage capacity multipurpose dam would be. If the dam were to release 10 m<sup>3</sup>s<sup>-1</sup> of outflow for irrigation (4000 ha) and environmental flow requirements, and if dry season irrigation were forbidden, there would be a sufficient supply of water for irrigation in the Ndembera sub-catchment and to allow downstream flows (see Figure 49 and Table 29).

Table 29: Scenario 3, sub-catchment flows before and after water abstractions, irrigation water demand and the number of days the irrigation demand is not satisfied (totally or partially).

SC	Wet season average flows before abstractions (m <sup>3</sup> .s <sup>-1</sup> )	Dry season average flows after abstractions (m <sup>3</sup> .s <sup>-1</sup> )	Wet season average irrigation demand (m <sup>3</sup> .s <sup>-1</sup> )	Dry season average irrigation demand (m <sup>3</sup> .s <sup>-1</sup> )	Wet season Number of days the irrigation demand is not met	Dry season Number of days the irrigation demand is not met
Itambo	14.45	3.66	4.12	3.85	37	174
Chimala	8.05	1.63	1.00	0.83	14	28
<b>Great Ruaha</b>	28.15	4.15	3.30	1.85	17	30
<b>Kimani</b>	11.24	2.25	2.12	1.19	16	28
Mlomboji	11.24	2.25	0.02	0.00	0	0
<b>Mbarali</b>	24.00	7.56	7.44	4.26	18	28
Kioga	25.77	5.33	3.57	2.19	5	16
<b>Ndembera</b>	14.52	11.15	3.11	1.73	0	2
North Eastern	4.17	0.86	0.00	0.00	1	3
Kimbi	22.46	2.03	0.02	0.01	6	20
North Western	31.31	5.06	0.25	0.14	1	3
Total	197.90	47.87	24.94	16.06	115.00	332.00

Table 30: Scenario 3, inflows and outflows of the Eastern wetlands and inflows to the Ruaha National Park.

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
<b>Total inflow to eastern wetlands</b> ( $\text{m}^3.\text{s}^{-1}$ )	10.9	31.7	50.2	88.4	111.4	107.7	50.2	15.7	15.4	16.3	19.5	15.9
<b>Outflow of the eastern wetlands</b> ( $\text{m}^3.\text{s}^{-1}$ )	1.4	9.2	29.6	42.5	65.4	79.6	66.8	36.0	24.3	11.1	9.9	7.5
<b>Inflow to RNP</b> ( $\text{m}^3.\text{s}^{-1}$ )	1.0	7.8	26.7	37.6	58.8	72.5	62.0	33.6	22.4	9.6	8.6	6.6

Table 31 shows that using the vision scenario input parameters, sufficient inflows to the Eastern Wetlands and RNP would be enabled. Considering that the overall objective of the measures envisaged by the RBWO is to restore year round flows to the RNP, RUBDA was able to show that implementing the vision's measures, as they were envisaged, would likely result in success.

Table 31: summary results of the number of days the Ruaha River dries up in the RNP for the three scenarios

<b>Number of days Minimum Required Flows not met during the dry season (out of 215 days)</b>			
	<b>Scenario 1 Natural</b>	<b>Scenario 2 Current (2002/2003)</b>	<b>Scenario 3 Vision</b>
EFR for the Eastern Wetlands ( $7 \text{ m}^3.\text{s}^{-1}$ )	25	124	0
EFR for the Ruaha national Park ( $0.5 \text{ m}^3.\text{s}^{-1}$ )	0	90	0

According to RUBDA, limiting water uses in the sub-catchments and building a large dam on the Ndembera River would be sufficient actions to ensure the restoration of downstream flows. It is interesting to note that the natural condition scenario shows that even with no human abstraction, the environmental flow requirements for the Eastern Wetlands of  $7 \text{ m}^3.\text{s}^{-1}$  would not be met for 25 days of the dry season (table 7.16). The second scenario using the current data for 2002/2003 generated results that reflect rather well the situation of the Ruaha River at this time. RUBDA indicated that the EFR would not be met for 90 days of the dry season, which corresponds with actual measurements taken between 1<sup>st</sup> November 2002 and 31<sup>st</sup> September 2003 (the hydrological year used

in RUBDA v2), indicating that there were approximately 72<sup>18</sup> days of zero flow at the Jongomero camp, in the RNP.

It is important to note that although the modelled water vision could successfully restore downstream flows, its implementation would in reality be much more challenging. This is because the implementation of the water vision assumes that:

- Water demand will not increase significantly in the UGRRC
- A relatively large regulatory dam (of 216 Mm<sup>3</sup> storage capacity) will be constructed on the Ndembera River
- The construction of the dam will not generate an increase in the water demand during the wet season
- The dry season restrictions put in place in the Great Ruaha, Kimani and Mbarali Sub-Catchments will be implemented, for which the RBWO will rely on the creation and/or the empowerment of SCWUAs.

The “characteristics” of the vision as described and successfully utilised in RUBDA reflect the “state of mind” of the managers during the last years of the RIPARWIN project. The managers’ aims, constraints and means available for restoring flows in the Ruaha River evolved a great deal during the project lifetime of RIPARWIN, and they have certainly continued to evolve since then. For instance, although the initial plan of the Director of the RBWO was to build a small dam (50 Mm<sup>3</sup>), a preliminary study conducted by Jones (2008) using RUBDA concluded that this solution was unviable because it would allow insufficient water downstream to the wetlands and an insufficient water supply to the irrigation schemes throughout the year. The use of RUBDA to explore questions through running various scenarios will therefore assist managers by providing them with information that can enhance their understanding of the UGRRC system and allow them to assess the potential impacts of decisions they may take.

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<sup>18</sup> Sue Stolberger’s records at Jongomero Camp in the Ruaha National Park (UTM: 679147E 9127828N)

### **6.5. Evaluation of RUBDA v2 using Mysiak (2005) evaluation grid**

This section presents the results of the implementation of the evaluation grid proposed by Mysiak (2005) to evaluate decision support systems. The aim is to examine the ability of RUBDAv2 to fulfil its design purposes. Mysiak (2005: 204) shows that, in the literature, “despite the high number of DSS [or DA] developed, the risk of decision support systems failing to be up to the challenge of real-world problems is reported to be high”. This acknowledgment has motivated several authors to attempt to evaluate these tools. The type of evaluation and the criteria used were either defined empirically and/or defined by reviewing existing literature. Even the terminology used to “evaluate” is controversial, thus Nguyen (2006, p 34) who chooses to use the word “validation” (without clearly stating why) to examine three integrated system models applied to coastal zones in Indonesia notes the confusion generated by the divergence of terminologies and methodologies as follows: “The controversial debate on terminologies for model validation (...) points to the ambiguity and overlap between the terms: model testing, model selection, model validation or invalidation, model corroboration, model credibility assessment, model evaluation and model quality insurance” (Nguyen, 2006, p 34).

Mysiak (2005:205) claims that “despite the ambiguity of validity concepts developed so far, some of the success factors are commonly agreed upon”. In reviewing these factors, he produced a table presenting the various features and criteria used for the evaluation of decision support tools. He further identified five subjects that are validated using the proposed criteria or measurements. The subjects of validation and evaluation criteria are presented in Table 32.

The present section applies these criteria to evaluate RUBDAv2. The five subjects that need to be validated are about the different phases of the development of the DA and its different characteristics’, namely: Development process, DA components, decision process, decision output and user satisfaction.

Table 32: Validation and evaluation criteria used for the evaluation of DSS (Mysiak, 2005)

Subject of validation	Evaluation criteria
Development process	Involvement of future users in early development phases, appropriately defined system requirements, evolutionary system development, clear definition of beneficiaries.
DSS components	Precision of models, quality of data, user interface, reporting system to choice of suitable technology and management of data, complexity of DSS and data inputs.
Decision process	Appropriateness of logical process followed when using DSS, number of alternatives explored by DSS, internal communication, correspondence to and appropriateness for decision organisation.
Decision output	Quantification of profit/loss from DSS usage, consensus achieved among decision-makers, savings of time or other resources through DSS usage, contribution to organizational efficiency, consistency of solution.
User satisfaction	Degree of confidence in results derived by DSS, acceptance (willingness to change current management methods), improvement of personal efficiency, correspondence of DSS output with decision-making style, users' understanding of implemented models.

### 6.5.1. The Decision Aid Development Process

#### *Involvement of future users in the early development phases*

As one of the RIPARWIN project's outputs, the development of a DA for the management of water resources in the UGRRC was from the start of the project presented to a large number of stakeholders for their comments and contribution. As the initiative progressed, the variety and number of identified RUBDA end users decreased because of the narrowing down of potential end users through their involvement in continuous and increasingly intense interviews, workshops and above all, training. End users were given a number and variety of opportunities to express their needs and to comment and influence the design of RUBDA. Their participation started at the very early stage of the project (during the RIPARWIN inception phase), and on this basis, the criteria could be considered to have been met quite well.

During the first few months of the project, interviewees and workshop/training participants were satisfied by the proposed conceptual DA and validated its aims,

structure and functions. During the training that followed, participants (targeted end users) were satisfied by the different versions of RUBDA presented, because their requests were taken on board and the DA was modified accordingly. This was especially the case after the RUBDA v1 training, when some major changes had to be made which led to the development of RUBDA v2. These changes concerned a series of drawbacks in the model which ranged from bugs linked to the programming itself and also a major mismatch between the participants' requirements and the structure, the graphical user interface and the management of input and output data. These drawbacks were linked to the way RUBDA v1 was designed, though they could only be identified and corrected (at least partly) thanks to the continuous involvement of end users with RUBDA. David (2000) defines such a confrontation as necessary for the "contextualisation" of the tool.

### ***Appropriately defined system requirements***

RUBDAv2 did not need very powerful computers as the only main programs using resources were the FORTAN programs. The main issue concerning the system requirement concerned the operating system installed on users' computers. The information concerning the operating systems used was collected during the interviews during the design phase. The operating systems identified were Windows 98, 2000 and XP versions. RUBDAv1 was developed on Windows XP but some tests were realised on windows 98. The tests revealed some compatibility problems that were solved with RUBDAv2.

### ***Evolutionary system development***

The need for developing DAs for water resource management is due to the complexity of water systems and their changing nature. Indeed, there would probably be less demand for complex and integrated tools if managing water resources was a simple task. As a result, developing a DA is challenging because it requires modelling a changing system and requires building DAs that can evolve to fit these changes. The natural systems and the end-users requirements changes generally guide development such that developers must therefore find a way of coping with that situation and allow the decision aid built to evolve. The programming languages used (FORTRAN and

VISUAL BASIC 6.0) were chosen because there were some local staff (from the Sokoine University of Agriculture -SUA) being familiar with these languages. The aim was to ensure that once RIPARWIN finished, SUA would be able to maintain and upgrade RUBDA if required by the users. Nevertheless, the rather rigid programming style used and the high number of unplanned modifications made on RUBDA during and after the trainings have rendered some components more complex and not flexible enough to the point that it could be complicated for a programmer not familiar with the RUBDA to actually modify these components without generating numerous errors and bugs.

### ***Clear definition of beneficiaries***

In a similar manner to the narrowing down of the end users of RUBDA, the number of directly targeted beneficiaries decreased during the design process. It was initially planned that RUBDA would be used by all water-related stakeholders (including farmers) in the UGRRC, as well as being extendable to other basins in Tanzania. RIPARWIN aimed to develop a generic tool flexible enough to meet all stakeholders' needs, in line with the desire of the project's research partners to develop a tool addressing the principles of IWRM that would involve all the users in the management of water resources. As the project progressed the components and aims of RUBDA evolved and were refined. Its uses were defined by and for end-users from the river basin authority (the RBWO) as well as from the Mbarali District Council. Some technicians working in these two organisations were especially targeted as users of the tool, while others were perceived to be indirect users who would benefit from their colleagues' use of RUBDA. Water managers from these two organisations are major actors in the UGRRC, involved in formal water planning (see Chapter 4) and in taking decisions that have an impact upon water-users (although some claim that informal rules prevail). Therefore by improving the decisions taken by these managers through the use of RUBDA, it was assumed that all water users in the UGRRC would benefit.

## **6.5.2. Decision Aid Components**

### ***Precision of models, quality and complexity of data and data input***

The various hydrological models used in RUBDA were tested and validated when developed by the SMUWC project using sensitivity analysis and by comparison of simulated results and observed data. Because some models such as the Eastern Wetland model and the water demand model had to be updated and modified, the new versions were tested before being included in RUBDA. Once linked to each other and included in RUBDA, the models were tested as a whole from upstream to downstream in order to remove possible errors linked to the interactions between models (especially concerning the input/output of data stored in text files) and to compatibility problems linked to the dialogue between the FORTRAN and VB programmes.

Another important issue relating to the quality and complexity of data in RUBDA concerns the water demand. In order to answer requests made by end-users, some building blocks – which required a lot of input data – were developed to model water demand. Because some of the data regarding water uses, the population, the irrigated areas and the losses were lacking or unreliable in certain areas, the existing data for 2002/2003 had to be generalised and extrapolated to the areas lacking data. These data were then used as the default set of data in RUBDA. However, tests run with the default demand data and using the rainfall regime of the year 2002/2003 generated simulated river flows that were very close to the observations, and thus it can be stated that the use of such data was acceptable.

### ***User Interface***

The user interface was greatly improved during the development phase of RUBDA, especially through its upgrade from version one to two. Access to its different components and the “circulation” in RUBDA were improved thanks to the development of forward-backward buttons and intuitive menus which facilitated access to various windows and functions. The user interface was greatly improved by providing on the



same window the input data and results at the sub-catchment level. Navigation was likewise improved by the development of a help file as well as contextual help (when the cursor is hovering over buttons and functions). Efforts were made to offer several points of access to the various components of RUBDA through use of the toolbar menu or by use of buttons provided on the “child” windows. Nevertheless, there were some points that could have been improved, especially concerning the way priority and allocation strategies are set, and the way water demand is entered for the whole of the catchment and not for one sub-catchment in particular.

### ***Choice of suitable technology and management of data***

The developers had few options concerning the technological choices that had to be made. The programming languages were chosen because of the context, i.e. local knowledge of the programming languages and the existence of the Usangu Basin Model. Nevertheless, other components such as the Building Blocks used to generate water demands or the rainfall regime selection component were directly designed with the end-users themselves. The way data are managed in RUBDA – using text files and not appearing in an accessible database – was partly due to the way the hydrological models had been programmed by SMUWC (2001), but also due to problems that occurred when the development of the database began. The various local institutions (the Ministry of Water and Livestock, Regional Hydrological offices, the Ministry of the Environment, etc.) owning data did not want to allow the developers to provide direct access to the data through the database to end-users because of the data’s monetary value. This is because several of these institutions collect revenues from selling the data they collect.

### ***Complexity of the Decision Support System***

Great efforts were made to render RUBDA as simple as possible by providing a user-friendly interface, by removing all modelling components that were of no interest to users, and by removing some of the components of RUBDA that did not specifically address users’ requirements, such as the Outcome Model that modelled the socio-economic impacts of water uses – see chapter 6. One of the key trade-offs that existed during the development of RUBDA was between precision and simplicity of the data

and models used. The DA needed to have sufficient spatial and temporal detail and model complexity to accurately represent the UGRRC system, yet it needed to achieve this in a fast and responsive manner with a minimum amount of data. The strategy adopted by the developers to answer as best as possible the various requirements of potential end-users (from various organisations) rendered some components of RUBDA a bit complex, such as the Building Blocks used to manage water demand. The complexity of the hydrological system (comprising mountains, several rivers, alluvial fans, a floodplain and wetlands) also had an impact on the complexity of RUBDA. Nevertheless, efforts made in the development of the user interface simplified as much as possible the way catchment's modelling was presented to end users. The identification of the type of results and indicators that were of most use for end-users also contributed to the simplification of RUBDA.

### **6.5.3. Decision Processes supported by the Decision Aid**

#### ***The appropriateness of the logical process followed when using the Decision Aid***

To be appropriate, the logical process followed in RUBDA must be understood, supported and inline with the logical processes followed by end-users when managing water resources. The appropriateness of RUBDA and its effective use for planning rely on its capacity to represent the real world in a way that corresponds to how end-users perceive reality.

The main intended end-users of RUBDA are the “top five” managers working in the regional offices of the RBWO and the Mbarali District Council officers involved in water management. Most of these managers are high-level technicians taking decisions regarding water uses, restrictions and planning. However, a few of them also have a more political and “policy” dimension to their work, such as the Director of the RBWO. RUBDA was intended to assist these managers in their mission to manage the water resource of the Upper Great Ruaha River Catchment. To this end, RUBDA focuses on generating information at the sub-catchment scale to provide its end-users with some means of issuing water permits to SCWUAs, and more generally to enable them to

reflect upon the impact of the decisions they take regarding planning activities (mainly restrictions and choices regarding the development of sectors that use water).

The logical process followed in RUBDA when running scenarios and assessing their impact can be considered appropriate. Indeed, it provides means for running scenarios at the sub-catchment scale and provides results using indicators (river flows and volumes used and available, zero flows, wetlands and Ruaha National Park flow requirements, etc.) that fit the nature, format, and scale of the information required by the end-users. The way the UGRRC was sub-divided (sub-catchments, floodplain, wetlands, National Park) and displayed in RUBDA aimed at imitating the way it is divided by the managers. It was critical, also, to ensure that the acquisition of inputs and the outputs generated (results) were displayed at scales that fit the “management units” used by the end-users.

Regardless of the efforts made to sub-divide the UGRRC adequately (as outlined in chapter 4) the RBWO requested that two of the 11 sub-catchments used in RUBDA be redefined and divided into six smaller sub-catchments. Thus the RBWO identified 15 sub-catchments as being the correct units for managing the water resources of the UGRRC. Their request was declined [or RUBDA’s designers were unable to meet their request], and as a result two sub-catchments are used in RUBDA that do not fit the ones identified by the RBWO, namely the Itambo and Western sub-catchments. Otherwise the hydrological units (higher parts of sub-catchments, plains with water uses, results at the sub-catchment level, and upstream/downstream of wetlands, etc.) correspond to the management units for the RBWO.

Although the original hydrological model (UBM) used in RUBDA was developed using historical data and provided the means for running long time scenarios by using day steps, it was decided after careful discussion and consultation that RUBDA should be simplified to better answer the needs of managers by using monthly steps and by running for a one year period. The models still run using daily steps and irrigation demand using 10 day steps but the input and output data are displayed as monthly values for end users. The level of detail that was initially identified by researchers as suitable to represent the UGRRC system (daily step) was too high and generated too much information to be truly useful for managers. By changing the time scale, RUBDA

lost some of its precision but was made easier to use. The lack of reliable and precise data concerning water demand was another motivation for reducing the precision of the models, for it became useless to model variations of river flows on a daily time step while water demand was being entered on a monthly step and as a result was not very precise.

The fact that RUBDA in its second version can be considered easy to use and purposeful is a direct outcome of the important shift that occurred between version one and version two. The developers attempted to change RUBDA from being a research tool to becoming a policy tool (see Chapter 6): From being a modelling-centred DA to becoming a user-centred DA. In the second version, the choices concerning the level of detail, the complexity and the type of data used and generated were dictated by the problems faced by end-users who were in need of solutions.

Nevertheless, some specific points remained a little unsatisfactory, for instance the way water rights are used. The incorporation of water rights was problematic because of the lack of available data and errors in existing data. Furthermore, although water rights were identified as important, they are not used as a management tool by decision makers.

### ***The Number of alternatives explored by the Decision Aid***

Of the several parameters that can be modified to create scenarios, the main ones are: rainfall regime in the plains or in the higher parts of the sub-catchments, water demand, environmental requirements and water allocation rules and strategies. By selecting different values for these parameters, a virtually unlimited number of combinations can be modelled by RUBDA.

In addition, there are certain issues that may require specific uses, for instance:

- The building of a dam on a specific river would require significant modification to the hydrological models and would therefore become a specific application of RUBDA, not merely another scenario

- The optimisation of water uses in order to ensure targeted downstream flows cannot be considered as a scenario in RUBDA but would require users to run the models several times by modifying the input parameters to get the targeted flows.

### ***Internal communication and consensus building***

These two criteria are treated as one here, although they appear in two different validation subjects in the evaluation grid proposed by Mysiak (2005): Decision process and decision output. Mysiak (2005) included internal communication as an evaluation criterion for DSS. But this criterion is particularly relevant when a decision aid is developed for big structures and organisations where the decision aid must be included and facilitate the communication between the different departments, teams or managers that are involved in the decision process. This criterion is less critical in the case of RUBDA because the targeted organisation is small in size and number of staff. Yet the capacity of RUBDA to generate communication and assist in consensus building among managers from the RBWO and between other actors of the water sector, e.g. from the district councils or the water board, is important. This role can be endorsed by RUBDA because it is a tool for common knowledge building. Rather than being a tool used to answer a specific question for which end-users require a precise answer in order to take action, RUBDA enables an enhanced shared understanding of the hydrologic-agronomic and ecologic system. Thus, it can be classified as a tool for “building common references that enable collaborative actions and decision making” or, as defined by Beuret (2006), a dialogue tool.

#### **6.5.4. Decision output**

The criteria given under the decision output subject by Mysiak (2005) do not fit very well with the DA being evaluated here. These criteria are: a) quantification of profit/loss, b) savings of time or other resources through usage, and c) contribution to organisational efficiency or the consistency of the solution. These criteria rely on the idea that the DSS (or DA) is designed to assist end-users to perform specifically one or several tasks and that the DA will provide ready-made answers or at least elements that directly allow decisions to be made. This implies that the DA can provide consistent

solutions, thus improving the undertaking of the aided task, and by doing so will contribute to organisational efficiency. Yet RUBDA is not a DA that provides “optimum” solutions. Rather, it explores various solutions and generates information that can assist the RBWO to explore possible scenarios and enhance its understanding of the UGRRC system. These criteria would thus have been suitable to evaluate RUBDA if its objectives had remained to assist in particular tasks to be undertaken by end-users, for example the delivery of Water Permits to individuals or to Water User Associations. Yet, and as became clear during the participation phase and training sessions, there are no particular decisions that end-users take that would require the use of a DA. Thus, the Director of the RBWO once mentioned that although he needed RUBDA to gain knowledge and to run scenarios, he mainly needed RUBDA to provide scientific weight to his decisions and to gain influence and power on the political arena at the national level. Thus for him, RUBDA’s scientific results provide the confidence he requires during negotiations or when he has to defend his decisions in front of other managers, policy makers and politicians.

#### **6.5.5. User satisfaction**

##### ***The need for a post-implementation evaluation***

The last subject of validation identified by Mysiak (2005) is very important since it is about user satisfaction. User satisfaction can be evaluated using five different criteria that are best measured by end-users themselves. The main evaluation of RUBDA by end-users was done during the three training sessions held during the development of RUBDA. These evaluations did not directly assess the final version of RUBDA. Nevertheless, its effective use could be observed and analysed in August 2007 during a one month field study in Tanzania that aimed at using the Dam Programme and RUBDA to assist the RBWO in assessing the possibility of building a dam on the Ndembera River. Although the study involved the extensive use of RUBDA (see Jones 2008) by researchers (not by RBWO end-users), one of its aims was to investigate whether RUBDA had been used, and how it had been used, since it had been handed over. The factors that impeded the actual evaluation of use by end-users were computer

problems (viruses, and the necessary reformatting of machines) and the lack of commitment by some staff (pre-retirement age).

Therefore, the evaluation of end-user satisfaction reported here is a mix of indirect feedback and out-of-context comments which may not yield as rigorous an evaluation as desirable. There are actually very few examples of DAs or DSSs that have been evaluated in their post-implementation phase. Most tools are declared a success at the end of their development phase once handed over to end-users. Kohli (2004, p104) declares that “traditionally” DSS evaluation research has focused on the justification, deployment and usage of systems but not on their implementation. Such research tends to justify the investments necessary to develop DSS through cost-benefit analysis or by proving the “value” of the DSS.

### ***The degree of confidence in results derived by the DSS***

The degree of confidence in the results was tested on several occasions during the training sessions when trainers or participants had to run scenarios. The results of these simulations were discussed and sometimes challenged but were overwhelmingly accepted. Some doubts were expressed by participants who had been SMUWC targeted end-users when the UBM had been developed. They still had in mind that the UBM generated river flows that were overestimated in some of the sub-catchments and did not therefore represent flows inline with the observed scarcity of water during the dry season. These overestimations of river flows had three causes: a) the rainfall-runoff data and models used, b) an underestimation of water uses in the various sub-catchments, and c) the lack of accuracy of the equations used to model the Ihefu Wetlands. These three issues had actually been addressed in RUBDA by including rainfall data from stations located in the downstream part of the sub-catchments (where rainfall is lower), by putting a lot of effort into the estimation of water uses, and finally by changing some of the parameters of the Eastern Wetland Model based on new research work realised by the RIPARWIN project. Once this was clarified, the degree of confidence was found to be acceptable.

### ***Acceptance (willingness to change current management methods)***

The acceptance of RUBDA by end-users, either from the RBWO or from the Mbarali District Council, was rather difficult to evaluate because of limited actual use at the very time of evaluation. Nevertheless, and once again on the basis of what was observed during the design and development phases, it can be noted that the enthusiasm shown by most end-users and their willingness to acquire a tool that would assist them in their everyday work activities is a positive sign of acceptance. Foremost, the discussions and debates held between researchers and end-users and between end-users themselves during the various workshops, interviews and training sessions had already contributed to changes in the current management methods. It is very difficult to assess the real impact that the development of RUBDA had in these changes but it certainly had some impacts. Between 2002 and 2007, there have been clear signs that water resource management in the UGRRC has changed. These changes concerned for instance the review of the water rights, the efforts made through canal regulation activities to throttle intake flows during the wet and dry season and the push made by the RBWO to get farmers and other users to create sub-catchments Water Users Associations (Apex)<sup>19</sup>.

### **6.6. Conclusions**

The calibrating and performance testing of RUBDA v2 has produced the following findings: (1) Users' feedback could easily be taken into account in adjusting the hydrological model and designing interfaces and outputs. (2) The three scenarios run have shown that RUBDA v2, as far as modelling is concerned, is appropriate for simulating the various hydrological components of the UGRRC, including water demand and use. (3) RUBDA v2 agrees with the RBWO's request to determine water distribution objectives at the sub-catchment scale and thus serves a more global objective of restoring water downstream to the wetlands and the RNP. (4) The results generated by RUBDA v2 enable users to test various scenarios of water distribution at the sub-catchment level and to assess their impacts on water demand satisfaction as well

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<sup>19</sup> See Chapter 3 for more informations on Sub-Catchments Water Users Associations



as on downstream hydrology. (5) The third (vision) scenario showed that the RBWO strategy could restore year round flows in the RNP.

Although RUBDA v2 was successfully used as a simulation tool, it still suffers from several weaknesses. Specific parts of the study had to use separate simulation programmes, e.g. the modelling of the Ndembera River Dam. The production of graphs was completed using Excel by manually exporting data from RUBDA v2, and some further modelling had to be done to simulate low outflows from the Eastern Wetlands ( $< 0.5\text{m}^3.\text{s}^{-1}$ ).

To facilitate the practical use of RUBDA, therefore, some improvements could be made. The main flaws that can still be observed when using RUBDA v2 are as follows:

- There remain some “bugs” linked to programming errors,
- The Dam Simulation Model developed for RUBDA was not integrated into the system because of time limitations,
- Results, scenario parameters, water demand and supply for different sectors, and flow requirements met or unmet, cannot be exported easily,
- The “priority and water allocation strategy module” must be improved (same water allocation rules currently applied to the entire UGRRC whereas the module should instead enable users to define different strategies for differing sub-catchments, as the RBWO clearly does in reality),
- Two of the sub-catchments used in RUBDA v2 do not correspond to the sub-catchments used by the RBWO, and the RBWO claims that these sub-catchments are too big to be managed; thus these two sub-catchments should each be “divided” into three smaller sub-catchments.

RUBDAv2 was further tested using the evaluation grid proposed by Mysiak (2005) to evaluate Decision Support Systems. Mysiak (2005) identified 17 criteria that represent the agreed success factors and grouped them in five categories. Evaluating these criteria should reduce the chances of failure of a Decision Support System. RUBDAv2 was evaluated using the criteria and, apart from certain technological choices made and some scale issues concerning some of the sub-catchments used, it showed that RUBDAv2 passed the evaluation successfully.

The tests run on RUBDA v2 have shown that, although it can still be improved, RUBDAv2 can act as a decision aid and assist the RBWO in its mission of managing water resources in the UGRRC. A considerable amount of work was achieved during the three years of the development phase to get to the version of RUBDA tested in this chapter. As described in chapters 4 and 5, a series of interviews, workshops and trainings were organised with the targeted users and efforts were made to continuously improve RUBDA. Several versions were developed in an attempt to improve the tool to answer the requests and requirements made by the users. The development methods used to develop RUBDAv2, a participative design and software project management can therefore be used to develop Decision Aid that fit the operational context of water resources management.

## **Chapter 7 - Discussion and conclusion**

### **7.1. Introduction**

In this final chapter, the main findings of the thesis are summarized and discussed, in order to identify lessons and wider perspectives. The objective of the present work was to assess the development and application of a Decision Aid (DA) tool for water resource management in sub-Saharan Africa, with particular emphasis on the understanding of the needs of end-users and their engagement in the DA design. The design and development of the DA, called the Ruaha Basin Decision Aid (RUBDA), was achieved as part of a DFID research project conducted over a period of approximately five years. The project was conducted in an iterative manner using different methods of end-user participation and action-research, as well as different DA development methodologies.

The following specific research questions were formulated and constituted the framework of the thesis:

- Question 1 - What are the demands and constraints for designing a DA for water resources management in the context of IWRM?
- Question 2 - How does the operational context and practical demand of water resource management interact and influence the development of a DA?
- Question 3 - Can existing development methods be used to develop a DA that fits the operational context of IWRM?

The following paragraphs will revisit these questions and show how they have been addressed.

The thesis highlights the challenges inherent to the development of DAs that are designed to meet their purposes and answer users' needs. The study also shows the complexity of the water resources framework within which water resources managers operate and water resource DAs have to be "inserted". Building upon an abundant literature reporting on reasons for the non-use of DAs, the research explored how the involvement of end-users would influence the design and development of RUBDA and therefore contribute to its performance. The first version (RUBDAv1) can be considered a "Research DA", or "model-centred". It was based on researcher-designed

specifications aiming at improved water management by local users. Following users' feedback, the potential of using methods derived from software project engineering was examined to better capture end-user requirements and thus improve on the development of the tool and its performance. This led to the development of a second version (RUBDAv2), which can be described as an "Exploratory DA", or "user-oriented", effectively assisting institutions to manage water resources. This progressive conceptualisation of the DA directly answers Questions 1 and 2 through the careful verification of users' expectations, skills, limitations and constraints. Taking into account the working context of potential DA users and of water management operations strongly influenced the development of the DA, which ended to be something rather dramatically different from what was initially envisaged. Throughout the successive phases of the project, insights into the science of development of DAs were generated.

Research results reported here contribute to enhanced knowledge about i) the detailed understanding of the needs of water resources managers from river basin authorities in sub-Saharan Africa, and ii) the development of DAs for water resource management. The findings reflect the methodology that was adopted (action research) since they generated knowledge that is relevant both for implementers (action) and for researchers (theory). Specifically in the sub-Saharan African context, these needs appear to be (1) difficult working conditions for staff of water management agencies, (2) poor quality of infrastructures and (3) equipment and changing institutional framework (formal and informal), sometimes affected by political decisions. It thus appears – and this is a direct answer to Question 3 – that existing development methods cannot be used as such but need to be adapted to conditions, infrastructures, equipment and local stakeholder context. The merging and complementarity between different approaches was the only way to address the many challenges met during the course of the research.

## **1.2 Summary of results**

This section presents a brief description of the main results of the thesis. Results showed that DAs are more likely to answer the needs of water resources managers if they are built as exploratory (user-oriented) DAs and not as research-driven (model-centred) DAs. The thesis therefore embraces David's (1996) call for a shift from prescriptive to

exploration tools. The case study showed that an early and continuous involvement of end-users during the design and development of user-oriented DAs is necessary but cannot ensure the development of “fit for purpose DAs” unless DA development projects adopt software engineering and project management methods to limit their tendency to answer the requirements of donors and scientists before those of managers. This result is in line with De Kok’s (2003) call for more end-user participation and project management as key success factors in the development of DAs. Although these methods (proven to be efficient in developed countries) are necessary and imply engaging software developers, their implementation in sub-Saharan Africa is limited by the context within which targeted end-users operate.

Developing an exploratory DA requires adopting characteristics of both research DA (as they have been developed in sub-Saharan Africa) and management DA (as they are developed in business organisations and industries in western countries). The question is not of soft complementarities between these two sets of characteristics but instead of an articulation between the two approaches. This articulation must attempt to identify at what moment one approach or the other can best represent and fit the system being observed and at what moment both approaches need to be engaged in order to develop an appropriate DA. The final version of RUBDA was tested with users and scenarios and showed that RUBDA v2, as far as modelling was concerned, was appropriate for simulating the various hydrological components of the UGRRC and that it could assist the RBWO in its mission of managing water resources in the UGRRC. Scenarios also showed that the implementation of the RBWO water allocation vision could restore year round flows in the RNP. An evaluation of RUBDAv2 against the evaluation grid proposed by Mysiak (2005) showed that, globally, RUBDAv2 “satisfies” the agreed success factors.

The research revealed as well that developing an exploratory DA is as much a means to interact with managers and generate knowledge concerning the targeted organisation as it is a means to generate knowledge for managers through the use of the DA. The next sections discuss the key findings presented above as they contribute to the opening of new perspectives for future research on user-oriented DA development for water resources management.

### **7.1.1. An exploratory DA in the sub-Saharan African context**

In the Sub-Saharan Africa context, exploratory DAs can answer the needs of managers struggling to manage water resources. The evaluation of RUBDAv2 (Chapter 6) has shown that RUBDA could be used to explore water management questions through the running of scenarios. This would assist managers by providing them with information to enhance their understanding of the catchment and by allowing them to assess the potential impact of their decisions. At the start of the project, the aim of RUBDA was to assist end-users to perform specifically one or several tasks and to provide elements directly allowing them to make decisions, if not providing ready-made answers. However, RUBDAv2 ended up with a different nature and purpose. It did not provide “optimum” solutions to assist in particular tasks. This did not result from any failure to capture users’ decision processes but from the fact that catchment managers that were targeted were not (or rather, not yet) in a situation to improve their productivity, nor to optimise their decision process or make it automated. Instead, they were struggling just to gain knowledge to take informed and acceptable decisions. In that sense, the thesis follows David’s (2000) call for providing managers with acceptable solutions, as opposed to optimised solutions. The research found that users did not have specific requests about task improvement. Their needs were about tools which could help narrowing down the knowledge gap that existed between water resource availability on the one hand, and water use and allocation on the other hand. This encapsulates much of the management context of water resources management in sub-Saharan Africa. This key result, which came during the first part of the study, forms the basis of the justification to implement research on an “Exploratory DA”, as opposed to a “Research DA” during the remaining part of the study. I believe that this finding has a generic value and is relevant for many IWRM projects in Africa as will be shown in section 7.3.2.

The above-described knowledge gap has various causes, such as; (i) lack of financial and technical means, (ii) lack of coordination between institutions (no data sharing) and (iii) the fact that river basin authorities are still quite recently constituted. This last point had a great impact on the role of catchment officers. For instance, the Director of the water office once mentioned that although he needed a DA to gain knowledge and run

scenarios, he mainly needed it to give his decisions scientific weight and to gain influence and power in the political arena at national level. The interplay between politicians and water officers is very common indeed, the former regularly trying to influence the latter. This was clearly observed twice during the research period. In one instance, the Ministry of Water requested that plantation dates be postponed on account of complaints from other farmers sharing the same water. In another case, the Prime Minister Office insisted that electricity be produced although dam levels were critically low.

With or without political pressures, water officers are in a difficult position to manage water because of the lack of technical and financial resources available to execute their tasks. They have to rely on pre-existing institutions at local scale and the capacity of these institutions to involve local communities. Community involvement is crucial towards the legitimacy of water officers to exercise their mandate, especially (i) the regulation of river water flow during the dry season, (ii) the collection of water user fees and (iii) the mediation and resolution of conflicts. At local scale, users rely on diverse customary (traditional) systems to get access to water (Rajabu and Mahoo, 2008; Maganga et al. 2002). Beyond a lack of means, the actual control of water resources by managers is thus hampered as well by the fact that the legal system which empowers water officers does not consider customary systems sufficiently. This dichotomy between legitimate (traditional) and legal (drawn from the law) water management is at the root of several RUBDA's problems with efficiency and acceptability issues. In addressing all these constraints, the exploratory rather than the research DA proved to be a more pragmatic and useful tool.

### **7.1.2.A Decision Aid by whom and for whom?**

DAs are required to assist in planning, designing, managing and operating activities in financial, commercial, engineering and other companies. In developed countries, DAs are generally developed by software engineers (developers) as part of projects where a target organisation is a client and the developer is bound by contract to deliver the tool. Software developers are often faced with domains they do not know and have therefore developed methodologies and tools to understand the “real” tasks achieved by software

users and their requirements. Software design as used in computing and business sciences tends to adopt a “project” approach, emphasising task analyses and usability. More importantly, norms have been created to ensure that users are satisfied by the product developed.

Because of the lack of internal financial capacity, institutions involved in water resource management in sub-Saharan Africa are not in a position to contract software development firms for the development of the DAs they require. Tanzania, like most sub-Saharan African countries, is highly dependent on foreign aid and has very low internal funds for investment in the physical and human resource capital required for water resource management. The lack of internal financial capacity to maintain and operate water management agencies further reinforces their dependency on external funds. As a result, donors are in a position where they have to finance not only the creation of new institutions but their functioning as well. The result is that donors promote the development of DAs that reflect their intervention strategies, such as the implementation of IWRM. Water managers may at best request donors to provide a DA but are not in a position to sufficiently influence the design of the DA according to their needs. Often, they are simply approached by projects which design DAs according to donors’ needs. Consequently, DA developers in developing countries have donors as clients, not targeted users who could influence DA design differently. Because of this situation, DA ownership/use and target users are not always clear.

### **7.1.3. Software project management methods: a means not a solution**

Using software project engineering and management approaches can improve the development of DAs. Yet, this does not mean that software developers and their methods will ensure the development of successful DAs. There are specific factors limiting the implementation of software project management methods for the development of DA in sub-Saharan Africa. First, these methods rely on the capacity of the client to validate and give new design or development orientations. However, when the beneficiary (i.e. the water officer) is not the client (i.e. the funding agency), this feedback mechanism is biased. Second, criteria used by water resources managers are



not easily modelled and are influenced by many reasons which may not be scientific or based on optimising resource use. Scarcity of good quality data further reinforces these problems. Developing an exploratory DA means taking into account the local context and available data in order to generate the maximum value from what is accessible. Software developers will tend to use this approach, while modellers will attempt to represent the modelled system as accurately as possible, even and often at the cost of collecting new data.

These difficulties in appropriately targeting the development of a DA were clearly observed during the present study. The software developer hired by the RIPARWIN project recommended that the number of targeted users (or institutions) be narrowed down, insisting on the need for different DAs for different users rather than a generic tool. However, Tanzanian institutions involved in water management are very small (e.g. about 20 people for the 175 000 km<sup>2</sup> Rufiji basin). Narrowing down the number and variety of users would imply developing a specific DA for almost every institution, a financially unrealistic solution. DAs developed for water management in Tanzania will thus continue to target as many users as possible. This is even strengthened by the nature of development projects going-on in sub-Saharan Africa that follow the recommendations and philosophy of IWRM: all stakeholders must be involved in decision-making and decisions must be taken at the lowest level possible.

The targeting of the DA towards optimizing resource use is another question at stake. While this objective ranked high among the software developer's criteria (as well as for researchers), it was of little relevance for end-users. This casts doubt on the use of some aspects of software project management methods for developing a user-oriented DA. These methods certainly are an appropriate means to investigate suitable DA characteristics, but not the solution for designing a final DA, because they do not include an "exploratory function".

#### **7.1.4.Exploratory decision aids: Building knowledge before making decisions**

The development of exploratory DAs is a research project in its own right. The working environment of water managers comprises multi-norms (formal and informal) environment with high social, political and external (from donors and NGOs) influences, in a context of growing competition (and legitimate concern) over limited water resources. Exploratory DAs are user-oriented tools that should enable users to increase their understanding of the system but more importantly, to explore potential solutions. In this sense, exploratory DAs borrow from research DAs their capacity to explore the reality and possible scenarios but go beyond this because the added value is not the modelling itself but the improved understanding it generates (as described by Oxley, 2004). This significant difference in design was the rationale for the evolution from RUBDAv1 (research DA) to RUBDAv2 (exploratory DA). The main characteristics of Research and Exploratory DAs are synthesised in Table 33.

Exploratory DAs borrow from companies' software development their capacity to adapt to users' demand by putting knowledge building for users at the forefront and modelling in the background. As outlined in management sciences (David, 1996; Roy, 1985) as well as decision aid sciences (Roy, 1985), exploratory DA are not management tools in the sense of performance improvement or resource use optimisation, but rather "companion tools" aiming at improving the understanding of users about resource use before assisting them to take informed decisions.

Table 33: Characteristics of Research versus Exploratory DA

Research DA	Exploratory DA
Process-oriented tool	End user oriented tool
Model-oriented interface	User-oriented interface: ease of use
DA most practical to develop	DA most appropriate for users
Optimisation of water resources management	Exploration of options, search for acceptable options
Top down	Bottom up
Prescription	Open and collaborative design
Developers as water experts	Developers as facilitators and knowledge builder based on constructive interactions
Managers learn from experts	
“Rational” modelling	Confronting actual behaviour and myth
Myth of managers as scientists taking scientifically sound and rational decisions	allows a new vision of actors’ constraints and objectives
Idealised behaviour of users	Operational reality of day to day role of managers
Decision sciences	Decision aid sciences
Normative approach	Science supports decision making

### 7.3. Relevance of findings

The findings presented in this report can be scaled-up to the development of DAs for the management of water resources in sub-Saharan Africa. The opportunity given by the RIPARWIN project has provided me with an opportunity to not only analyse but actually lead and participate fully in the design, development and evaluation of a DA. I used this opportunity to generate insights into the science of development of DAs for water management broadly speaking and to examine the ability of DAs to assist institutions in effectively managing water resources as well as fitting those requirements of integrated water resource management specifically.

### **7.3.1. Thesis contribution to research on DA development**

A key insight is that users' participation is necessary to improve DAs but does not guarantee that users' needs will be understood and "translated" into the design of DAs. Through the development of a specific DA, the aim was to improve the development of user-oriented DAs. By focusing on users' involvement and development methods, I assumed that DA's usage and efficiency were not as much dependent upon the quality of modelling or trust in the results as on the perception by users of the ability of the DA to generate new knowledge. Saying this does not mean that model development was undermined but that the requirements of modelling were kept to a minimum in order to allow us to focus on other issues. This implied repetitive running of the model and testing of results in order to verify that results generated by the different hydrological sub-models fitted observed data and did not interfere in the analysis. Thanks to this focus, this work generated findings concerning the understanding of users' needs and their involvement as well as about development methods that can benefit DA developers and contribute to the research on DA development.

There are lessons that can be drawn from the use of the V model that was applied as the life cycle model for the development of RUBDAv2. The V model presented advantages as it tends to reduce the "tunnel effect" where the client loses visibility on the project. Doing this reduced the risk of having clients discovering a product at the end of the tunnel that is not as expected. Nevertheless, its use relies on the strong definition of specifications during the initial phases of the evaluation and design. This task may be difficult knowing that it is often hard to transform users' expectations into specifications and that these expectations may vary during the project implementation. The experience gained in the case study showed that it is important to adopt the users' language to write the functional specification report (first phase) so that they understand what they are getting. This report must then be "translated" in developers' language to produce the design specification report.

Confronting and testing the DA using prototypes (paper, unitary and final prototypes) with users may provide means of validating and correcting the specifications of the DA

developed. In that sense, the real anticipation efforts made by developers using the V model to ensure that each phase ends with an adapted validation mechanisms is an essential advantage of this development model. It implies that both the mechanisms and the criteria that will be used to evaluate must be carefully defined. It may reduce the chances of having “surprises” and of having to rethink and redo any work.

Overall, the main factor which influenced project design was time. From the initial field surveys to the successive checking of the model by users through the various versions (including trial-and-error sub-versions) and training sessions, the overall development of the DA is a matter of several years. Inevitably, some other factors changed concurrently with time, for instance new water requirements emerged during the project, some stakeholders quitted and were replaced by others, etc. There is no simple answer to this time challenge. Perhaps a team work with clearly shared responsibilities among team members (e.g. field work, programming, training) would have made working conditions more realistic and time-efficient. This, nevertheless, does not match the working requirements of a PhD...

There are also some systemic problems with this type of development-oriented research. Funding agencies, for instance, are keen to dictate a demand-driven, problem-solving approach with quick “service delivery” and large scale replication. How many people have you reached? What is the area benefiting from the project? How much water has been spared? Who benefited from new water management decisions? Clearly, such questions cannot obtain ready-made answers provided simultaneously with research implementation. Although IWRM researchers should make every effort to produce results which have direct relevance to applied questions, it must also be accepted that there are sometimes some idealized conceptual visions of IWRM which do not match with the day-to-day reality on the ground. This is not specific to IWRM research. It applies to all sort of development-oriented research, especially in developing countries. An abundant literature has been written on the subject. A wealth of methods have been proposed, ranging from participatory approaches to adaptive co-management, “farmer first” options, scenario formulation, visioning the future and, of course, action-research. A common denominator to all these methods is a good amount of multidisciplinary, often giving a strong importance to social sciences. This, perhaps, should be given more weight in IWRM research.

### **7.3.2. Scaling-up: From the Upper Great Ruaha River catchment to sub-Saharan Africa**

Many of the socio-economic and institutional characteristics of the UGRRC in Tanzania are similar to those of other catchments or basins in sub-Saharan Africa. These characteristics can be summarized as follows:

1. Existence of diverse customary systems relied upon in getting access to and utilizing the water resources.
2. Management bodies empowered by the legal system to manage water resources but having a limited capacity to actually control water uses because this legal system seldom considers the informal (customary) systems sufficiently.
3. Significant lack of human, technical and financial means and resources.
4. Strong State and international injunction to implement reforms and perform informed management towards IWRM.
5. Strong social pressure observed by basin officers to respond to new demands such as climate variability and other requests of water users or politicians.
6. Existence of donor funded development projects proposing technical solutions in accordance with donors' agendas.

In the case study, these characteristics have had a direct impact on the way managers operate and on their needs concerning support tools such as DA. Since these characteristics are common to many regions in sub-Saharan Africa and the developing world, it is believed that this Tanzanian study has a wide implication to other such studies and projects in much of sub-Saharan Africa.

### **7.3.3. Relocating the development of DAs within the debates about the implementation of IWRM**

The results showed that, although IWRM was the overall framework guiding WRM in sub-Saharan Africa, applying the requirements of IWRM to the design of a DA resulted in the development of a research DA but not to the development of a management DA that fits the water resources managers' operational context.

The existing debates concerning the implementation of IWRM highlight the split existing between IWRM as a theory described and promoted by the international community on the one hand and the operational reality as performed by local water managers on the other hand (see section 2.4). As one of the instruments promoted by IWRM for its implementation is the use of DAs, the concerns regarding the applicability of IWRM, especially in developing countries (Biswas, 2004; Lankford et al., 2005) should be transposed to the development of DAs.

In the case study, there is a strong State and international injunction to perform informed management resources toward IWRM but water managers are in a difficult position to manage water because they cannot “control” sufficiently water resources. This is due to the lack of technical and financial resources available to execute their tasks and because the legal system (which adopted most of the concepts promoted by IWRM) does not consider the informal (customary) system sufficiently (Maganga 2002, Sokile 2002).

It was also observed that DA developers and project partners had to change their behaviour from being water experts (promoting IWRM) to facilitators. As facilitators, developers had to adopt an open and collaborative design, building upon their interactions with users to design the DA. Developers were then able to create a DA that was most appropriate for users instead of concentrating on modelling or theory. DAs should help go beyond IWRM concepts and really assist water managers. The IWRM conceptual framework does not answer the precise problems and questions that water managers are facing in the real and complex world within which they operate.

#### **7.4. Targeting practitioners: Lessons learnt and recommendations**

A first recommendation is that the development of a DA for IWRM should not be treated as a specific task isolated from its context but should be considered as a full-size, integrated project. This implies that an experienced project manager (as defined by project management science) be in charge. This person would be responsible for dividing design and development in phases with clear and achievable objectives as well

as organising validation mechanisms by clients or users. The choice of developing a research DA, a management DA or an exploratory DA must be taken at the beginning of the project. This will directly influence the approach chosen by developers when interacting with users or designing the DA.

A second recommendation is that beyond hiring hydrological modellers, one or several software developers must be in charge of designing and programming tasks. This is particularly important as far as model interfaces are concerned and will facilitate the development of user-oriented interfaces. When interacting with users, for instance during training, the “water expert” should endorse the role of facilitator and the programmer should endorse the role of “translator”. Debugging prototypes has to be done by the programmer, while getting the users to test the DA and to talk about the match between their requirements and the DA has to be done by the facilitator. The “water specialist facilitator” must remain as objective as possible, free of programming constraints and focused on getting users to cooperate and provide all the feedback needed. This role is critical because it will help the “software programmer translator” to understand all the characteristics of the local context as well as the users’ interests and culture. Translating the requests made by users into DA specifications then becomes the clear role of the software programmer.

This process has to lead to a conceptual model of the functions that need to be performed by the exploratory DA as well as the inputs, outputs and the way the DA has to interact with the user. It is only then that the facilitator can propose ways of entering the hydrological model of the DA. It is critical that the development of the DA follows users’ thinking before following the structure of the hydrological modelling components. The “failure” of RUBDAv1 was partly due to the fact that the interfaces and the path that users had to follow were strictly based on the structure of the hydrological modelling – normatively correct in science terms, but unhelpful for users. The various hydrological units modelled did not match the way users perceived the reality. The tasks of designing and programming the interfaces and the different components facilitating the human/computer dialogue should not be underestimated compared to the socio-economic and hydrological modelling.



Beyond the necessity of having a developer acting as a facilitator, there are key recommendations that can be drawn from the RUBDA case study to facilitate the interactions between “developers” and users. Firstly, each “interaction” method ranging from large workshops, trainings and focus groups to one to one interview has its advantages and drawbacks. For instance, the large workshops and seminars where the draft RUBDA was presented at the launch of the project were a good means to raise the awareness about the DA being developed. These workshops allowed the developers to understand the general perception of such tools and their perceived usefulness, they also allow potential users to raise their interest and get them involved. This may be critical as few interested and motivated users (sometimes called “champions”) may contribute more than a larger number of uninterested potential users. Large workshops and seminars are not appropriate to discuss the specifications of a DA with users because it does not provide sufficient room for discussion and some participants may not feel at ease to discuss or criticise in front of a large audience. It is therefore difficult to collect constructive and quality feedback during workshops and seminars. Communication is much easier in small group meetings with users and even more in one to one interviews. It allows the developers to interact much better with users, especially if hierarchy is strong in the targeted institution thus preventing technician and specialist to talk in front of their superior. This may be a key issue to consider especially in sub Saharan Africa where hierarchical structures are very pregnant.

Concerning interviews, the developers must measure carefully the trade-off between the level of detail they expect from the informants. It is indeed tempting to expect users to provide very detailed answers in order to ease the definition of the required specifications. This often prevents open discussions. The informants spend all their time discussing technical details of specific parts of the DA instead of looking at the overall aim and usefulness of the DA. Paper prototypes were very practical means to collect user feedback. Presenting the different versions of the prototypes to users during the development also contributes to getting users involved if they happen to see that their comments were taken on board and used to improve the tool. Group sessions are convenient to present prototypes if the number of users participating is comprised between 5 and 15. The training sessions organised on the different versions of RUBDA showed that about 15 participants still allows open discussions and ensures that the tool is properly tested and that most bugs/problems are identified. During training sessions,

the role playing games where participants are grouped and play with real case scenarios proved to be the most efficient way to get participants to interact and use the DA. It is also important to ensure as much as possible that the same participants are involved in the different phases of the users' participation process. Having users that did not attend previous training sessions affects working speed, as issues which have already been discussed need to be raised again. This is often a problem in large organisations in sub Saharan Africa, where training sessions are often perceived as an easy way of earning money through per-diems. There is therefore a turn-over, organised to ensure that as many staff as possible benefit from training sessions instead of privileging continuity and participation based on the relevance and interest of the participants.

Another recommendation is about the number and variety of users, which must be as narrow as possible – contrary to current understanding. One of the basic principles of IWRM is that all stakeholders of a basin must be involved in the management of natural resources. Naturally, scientists and donors push for the development of tools that can be used by all stakeholders. These potential DA users have varying needs. For each type of user, the DA should in principle be different. For example, a DA targeting farmers should be in local language and probably not computer-based. One could imagine building a tool with several modules, one for each type of user. However, the difficulties in building such a DA should not be underestimated! This naturally brings the question of the cost-benefit assessment of such tools. It can be anticipated without much doubt that the development of integrated, specific user-oriented tools, would probably result in higher initial costs. However, such costs could also be considered as a meaningful investment for better, higher long-term benefits. Whether cost-benefit ratios under these circumstances are within limits acceptable by institutions, donors and governments is an open question which lies beyond the objectives of the present study.

Finally, the use of different prototypes at different stages of the development is a very effective means to facilitate communication with users, get feedback and decide on new orientations. Each phase should therefore end with a presentation/validation of a prototype. Training sessions should be organised regularly in order to reduce the amount of work to be repeated in case some components of the proposed prototype are not validated. It is critical for potential users to have reasonable/realistic expectations of what a DA can achieve (developers must as well be honest about this).

## **7.5. Further research**

There are few signs indicating an improvement of the current conditions that exist in many river basins in sub-Saharan Africa: Extreme poverty, competition over scarce water resources, high demographic pressure and a weak institutional framework all contribute to a bleak future. Although there are debates that question the implementation of IWRM concepts, interventions are likely to continue towards a more comprehensive approach to water resources management. The consensus that IWRM should be carried out at the river basin level “has placed river basin management on the agenda of governments and international funding agencies and has led to many new river basin initiatives” (Molle et al., 2007: 609). This, in turn, calls for more water resources management DAs to be developed. The present case study shed light on the struggle experienced by water managers from such river basin authorities to effectively manage water resources. In that context, exploratory DAs can answer the needs of water managers.

Even if there are concerns about the mandate that these basin scale institutions must endorse in order to allow a more “polycentric” (stakeholder-driven, decentralized) management of water resources, there are chances that more river basin authorities utilising a formal, such as the RBWO, will be created in the next decades. There is therefore a critical question that needs to be explored concerning the long term presence of river basin authorities. These institutions, as showed by our case study, face a lack of legitimacy both at national and local level. This lack of legitimacy, combined with the lack of information, human and financial resources, puts managers in a situation where they cannot manage water resources effectively.

In the long term, river basin authorities are bound to become each a main water management agency. It is therefore important to conduct research on the conditions for their long term performance. This will depend on their capacity to get “inserted” in the legal and institutional framework in order to obtain the required legitimacy and the necessary means to execute their mandate as well as the capacity to interact with the informal framework that still prevails at local scale. As noted by Molle et al. (2007: 619) “moving toward sustainable river basin management requires much more emphasis

on developing, managing, and maintaining collaborative relationships for river basin governance, building on existing organizations, customary practices, and administrative structures”.

The funding of river basin management operations, out of user and polluter fees that had been envisaged, does not seem to be sufficient in basins facing widespread poverty and where most users are small scale farmers. The question of the financing mechanisms is therefore another critical issue that needs more research, especially when more and more decentralised institutions are involved in the management of water resources.

Yet, it can be hoped that these institutions will change and follow a trajectory that will in the long term tend to put managers in a situation of effectively managing water resources. Means of getting these institutions to progress along that trajectory must be identified. Meanwhile, the call for developing DAs (or IS in general) to support water managers will continue. Until these managers have reached the point where they have the means to manage water resources, exploratory DAs will remain as the tool that best answers their needs.

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## Appendices

### **Appendix A: Questionnaire (14/04/2004)**

The following questionnaire was preceded by a leaflet giving a short description of RUBDA. Different versions of the questionnaire were used.

#### **Questionnaire**

**1) General background information:**

- a) Name and position of respondent and date
- b) Name of organization, department/division
- c) Task(s) of organization,

**2) Task(s) of respondent's division/sector**

- a) Task(s) of respondent's division/sector
- b) Means and methods used to realize these tasks
- c) Scale of study, is the organization working at the river, village, sub-basin, district, basin, region or another level?
- d) What information and sources of information are used? needed but missing?

**3) Equipment (computer) used,**

If used, how powerful are the computers and how comfortable are you with using computers?

**4) Water Management Objectives**

Attached is a list with important water management objectives.

- a) Could you review this list to see if you agree with the objectives that are mentioned. Should certain objectives be deleted from the list or are certain important objectives missing?
- b) Could you please select three objectives from the list that are very important to you or your organization? Could you rank them?.
- c) For each of the selected objectives/issues, could you explain why this objective is important for your organization?

**5) Water Management Options**

Please select one objective. For this objective, address the following questions.

- a) Could you identify some options that are available to realize this objective? (Options are specific actions that will help to improve the water situation in GRB).  
What is good about these options? To what extent would they solve the

problem? Who is involved in the implementation of those options? Do you consider your objective to be attainable in the near future, or an 'ideal' that is something for the longer-term?

For the most promising options, please indicate:

- b) Who should be involved in the implementation? What role should these stakeholders play?  
*Who should be responsible for implementation? Limitations and constraints for implementation? Who should pay? Role of government organizations? What co-ordination is required from other organizations? What assumptions are you making and/or the precursors that need to be in place?*
- c) What could your organization do to ensure the implementation?
- d) Who do you think will support implementation of this option? Why?
- e) Who do you think will oppose implementation of this option? Why?  
*What might be done to meet the interests of opposing parties?*
- f) Could you identify some options that are mentioned in the discussion but that, in your opinion, would be counter-productive in improving the water situation in GRB? Could you explain what is bad about these options?

#### **6) Indicators in RUBDA**

Attached is a list of indicators that RUBDA will provide,

- a) Could you review this list to see if you agree with the indicators that are mentioned? Should certain indicators be deleted from the list or are certain important indicators missing?
- b) Could you please select the objectives from the list that are very important to your organization? Could you rank them? (including indicators that were missing according to the actor).
- c) In what format, unit and under what support (paper, computer based, scale of the result, presentation as graph or table...) would these indicators be the most useful for you?

#### **7) Scenarios in RUBDA**

RUBDA is a means of running scenarios in the GRB, what are the scenarios that would be the most useful for you or your organization.

#### **8) GIS viewer**

RUBDA is also providing a description of the basin using a GIS viewer that will allow the user to view and create maps. The description will be based on dynamic maps, enabling the user to click at key locations to obtain information. Possible information given on the map:

- Rivers: names and mean flow
- Towns: population, altitude, average temperature, average rainfall
- Land-use: irrigation (name, area, production and intakes), afforestation (area, name)...
- Roads

- Main water users
- Topography, Geology and morphology
- Climatic features

Could you review this list to see if you agree with the information that are mentioned.

Are certain important information missing?

Using this GIS viewer, would you or your organisation be interested:

- To create and print maps
- Create and print tables containing the information
- Add personal data into the database
- Other

**9) Stakeholder identification and stakeholders' relations**

- a) With what other organizations do you have regular contacts to address water management issues on GRB? Are you satisfied with these contacts?
- b) Please review our list of stakeholders that we want to interview. Are these indeed the main stakeholders involved in water management in GRB or do we need to add important actors? Why?

**10) Is there anything you would like to add on the development of a Decision Aid in the GRB.**

**List of important water management objectives:**

- 1) Management of water distribution in the dry season
- 2) Increase/decrease of irrigation abstraction volume rate and activities
- 3) Developing rainwater harvesting
- 4) Education of water users
- 5) Realistic allocation of water rights; devolution of water rights to sub-catchment level
- 6) Conservation of environment (wetlands, flora, fauna...)
- 7) Water for Hydropower stations downstream
- 8) Water for RNP
- 9) Improvement of water productivity in Irrigation, re-designing intakes to allow for water sharing
- 10) Development of water supply infrastructure (dams)
- 11) Clean Water close by for domestic needs
- 12) Water for livestock

**List of important water management options:**

- 1) Involvement of all stakeholders in apexes and water user associations
- 2) Conservation of water sources
- 3) Introduce by-law for water sources conservation
- 4) Elaborate land use plans
- 5) Set aside livestock grazing areas
- 6) Review available water resources
- 7) Review water right to conform to available water resources
- 8) Involve water users in allocating water right

- 9) Develop water control monitoring devices to ensure abstraction according to water right
- 10) Improve water management at the irrigation scheme level
- 11) Improve irrigation infrastructure
- 12) Produce low water demanding crops
- 13) Use conservation agriculture practices
- 14) Reduce irrigated land
- 15) Encourage formation and strengthening of WUA
- 16) Stakeholders to be trained on rain water harvesting
- 17) Construction of Chaco dams
- 18) Government should direct funds to construction of water harvesting infrastructure
- 19) Government should increase experts to train farmers on water harvesting techniques
- 20) Farmers be encouraged to contribute to construction of dams
- 21) Uprooting water depleting trees planting indigenous trees
- 22) Develop use of groundwater
- 23) Educate society on national water policy

**List of indicators in RUBDA:**

- 1) Water available at the basin level
- 2) Water available per capita
- 3) River flows in key points
- 4) Sectoral water uses at the basin level
- 5) Environmental flows requirements
- 6) Subsistence flow requirements
- 7) Irrigation flow requirements
- 8) Wet and dry season size of the wetlands
- 9) Area under different land-uses
- 10) Costs/benefits of rice production
- 11) Costs/benefits of water used for the HEP
- 12) Costs/benefits of water utilization in other sectors
- 13) Population benefiting of each water use
- 14) Maximum wet season abstraction rate currently (estimated to be about 50 cumecs)

**List of scenarios in RUBDA:**

- 1) Evolution of the rainfall: User sequence
- 2) Input at the rainfall stations: new rainfall data.
- 3) Input at the gauging stations: new flow data.
- 4) Evolution of the irrigated abstraction rate and area served
- 5) Evolution of the irrigation efficiency
- 6) Evolution of water abstracted for irrigation
- 7) Evolution of the Western floodplain (mainly using the threshold value)
- 8) Evolution of the Ihefu wetland area and flow routing characteristics
- 9) Policy driven scenario (refers to the main objectives chosen in question 4), this can assess the impact of policies that would be implemented to reach these objectives.

**List of actors that will be interviewed:**

- 1) RBWO Iringa

- 2) RBWO Rujewa
- 3) Mbarali District
- 4) Mbeya Rural District
- 5) RNP
- 6) Tanesco, Mtera/Kidatu
- 7) Tanesco, Dar es Salaam
- 8) MATI Igurusi

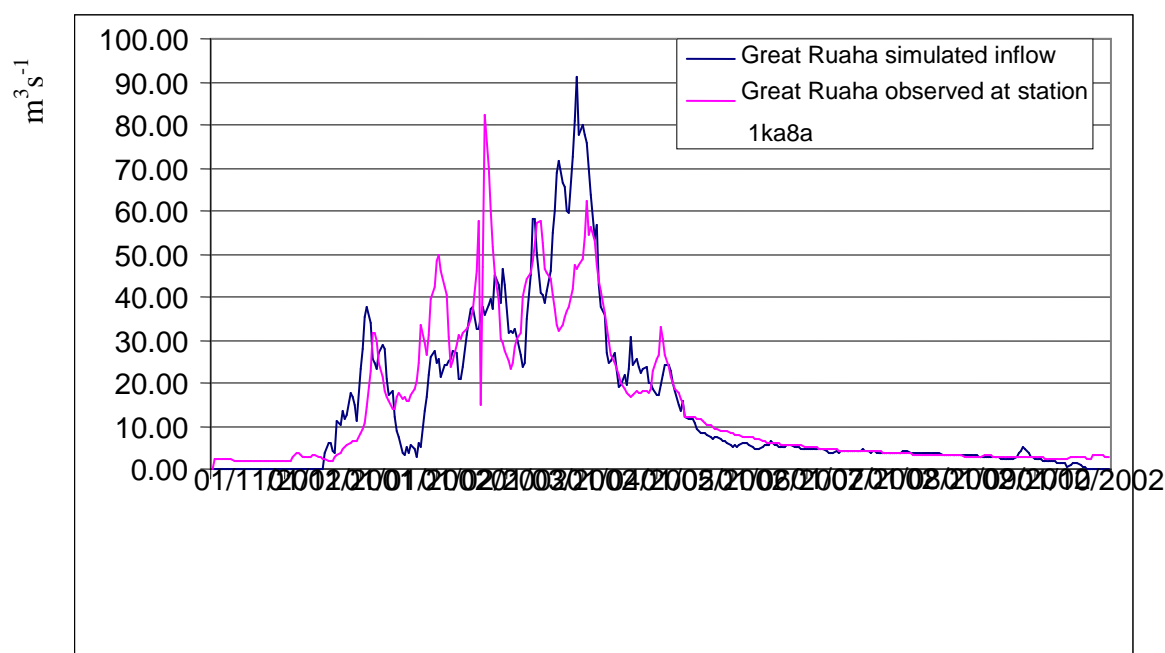
## **Appendix B: Results of the three scenarios run with RUBDAv2**

This appendix presents the results of the test run with the three scenarios (1.Natural; 2.Current; 3.Vision) and that are not used in Chapter 6.

### **Scenario 1: Natural flows**

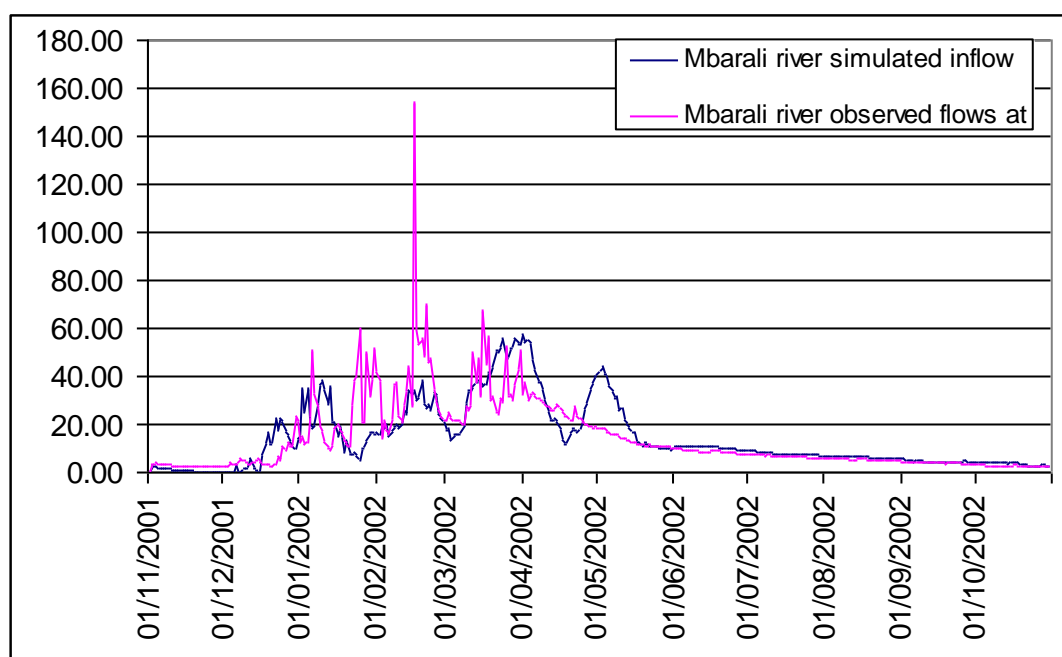
Great Ruaha river simulated and observed flows generated in the high Catchment.

Scenario 1

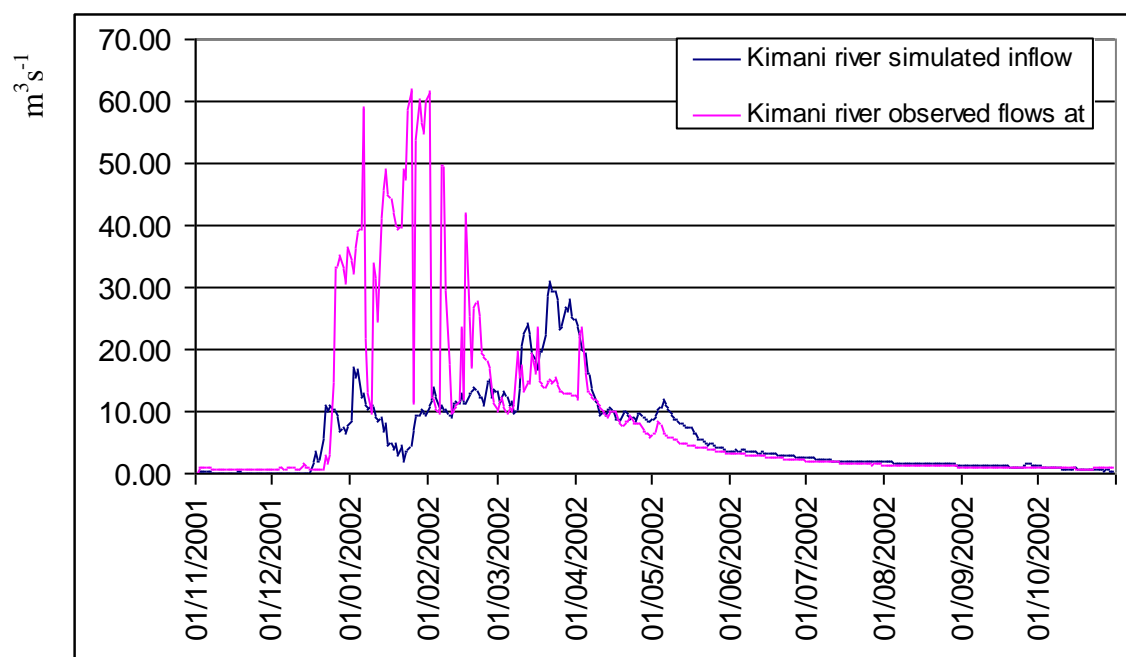


$\text{m}^3 \text{s}^{-1}$

Mbarali river simulated and observed flows generated in the high-Catchment. Scenario1

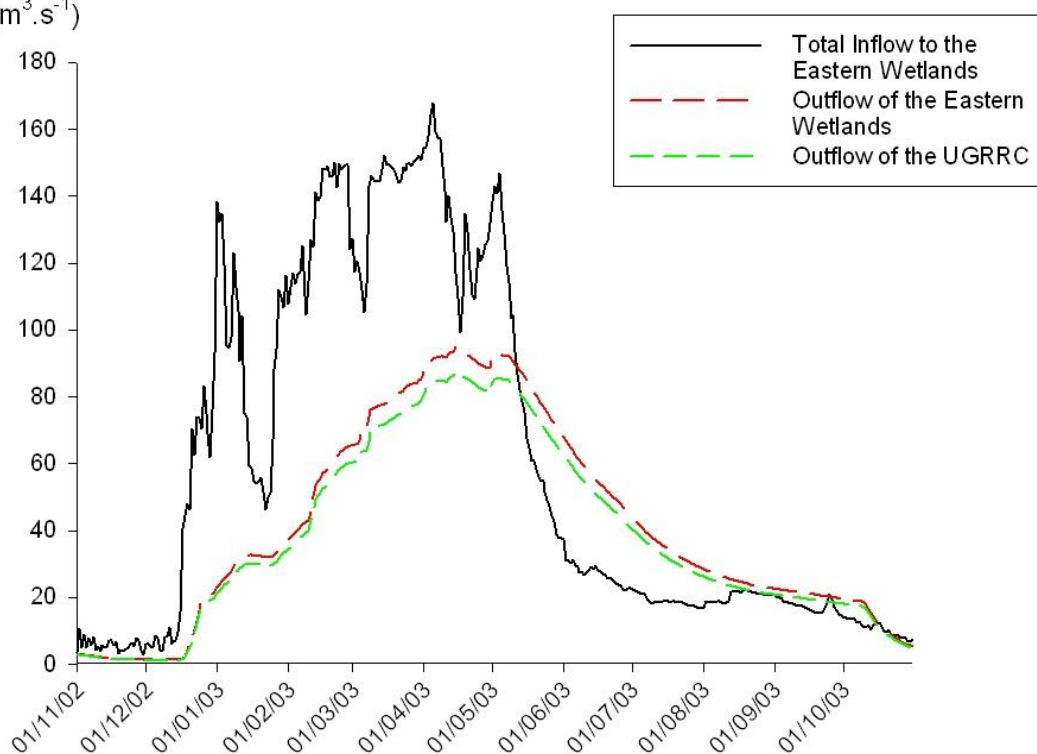


Kimani river simulated and observed flows generated in the high Catchment. Scenario 1



## Inflows and outflows of the Eastern wetlands and flows in the RNP. Scenario 1

Daily flows  
( $\text{m}^3 \cdot \text{s}^{-1}$ )



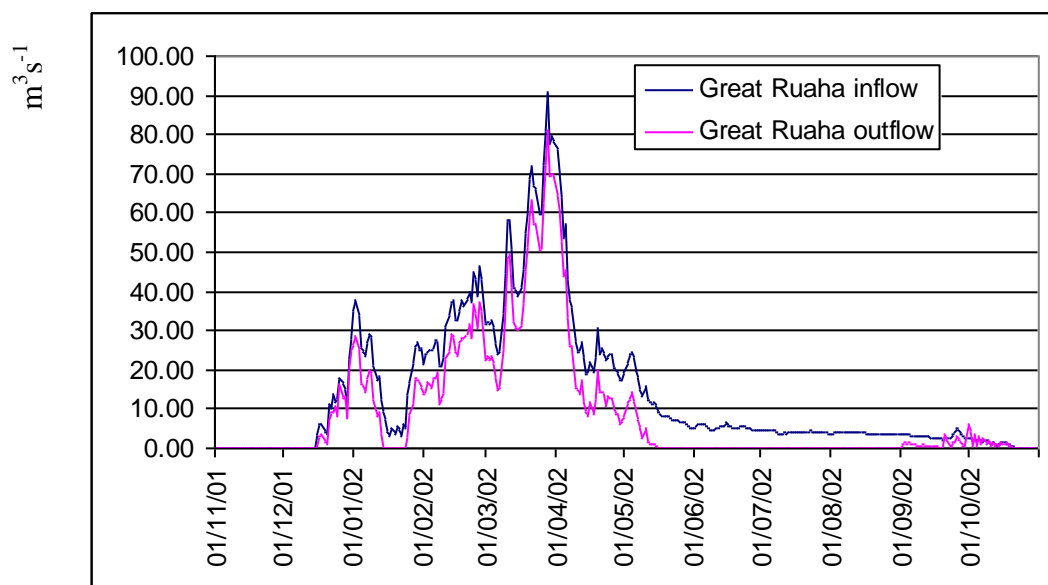
## Monthly averages of Inflows and outflows of the Eastern wetlands and flows in the RNP. scenario 1

	No v	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Total inflow to eastern wetlands ( $\text{m}^3 \cdot \text{s}^{-1}$ )	5.7	35.8	88.0	132.5	140.7	133.5	81.3	27.3	19	20.3	17.5	10.7
Outflow of the eastern wetlands ( $\text{m}^3 \cdot \text{s}^{-1}$ )	2.1	9.3	38.9	66.9	94.7	108.5	91.8	54.1	32.6	24.4	15.5	5.9
Inflow RNP ( $\text{m}^3 \cdot \text{s}^{-1}$ )	1.8	7.7	34.5	59.5	86.0	97.4	85.0	50.8	30.5	22.7	14.2	5.3

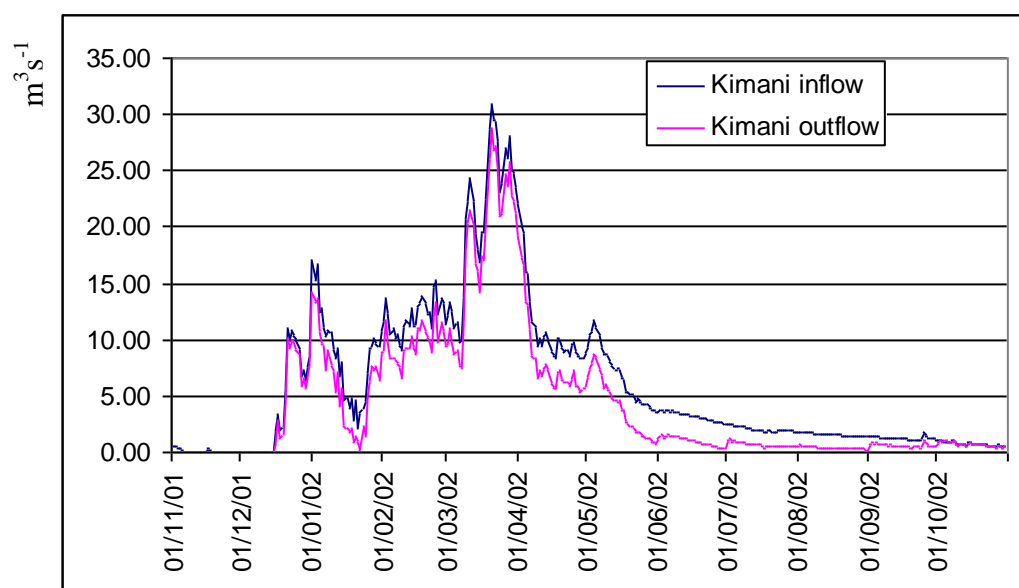
Dry season EFR met 190 out of 215 days

## Results current scenario

Great Ruaha SC simulated inflow and outflow. Scenario 2

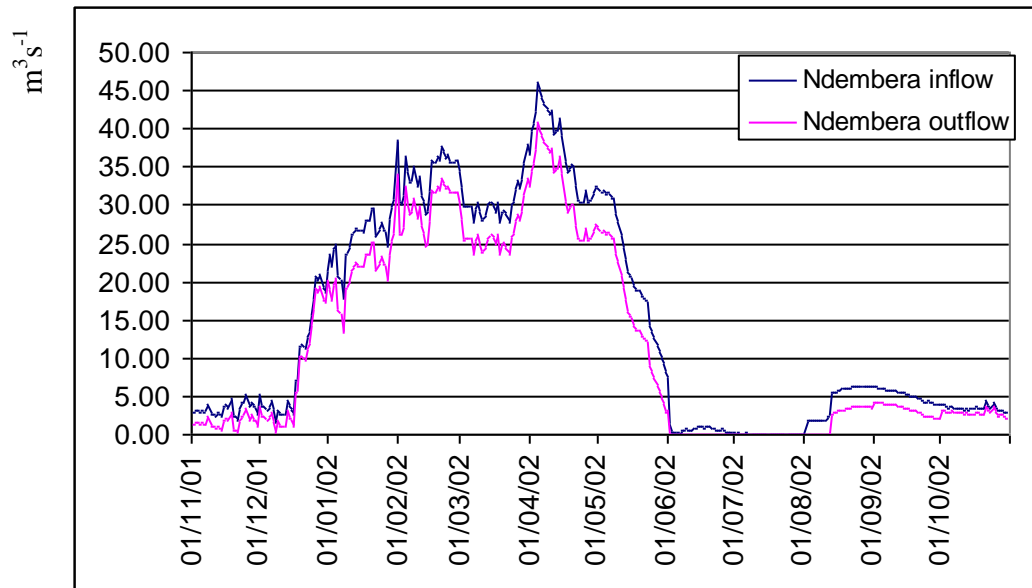


Kimani SC simulated inflow and outflow. Scenario 2

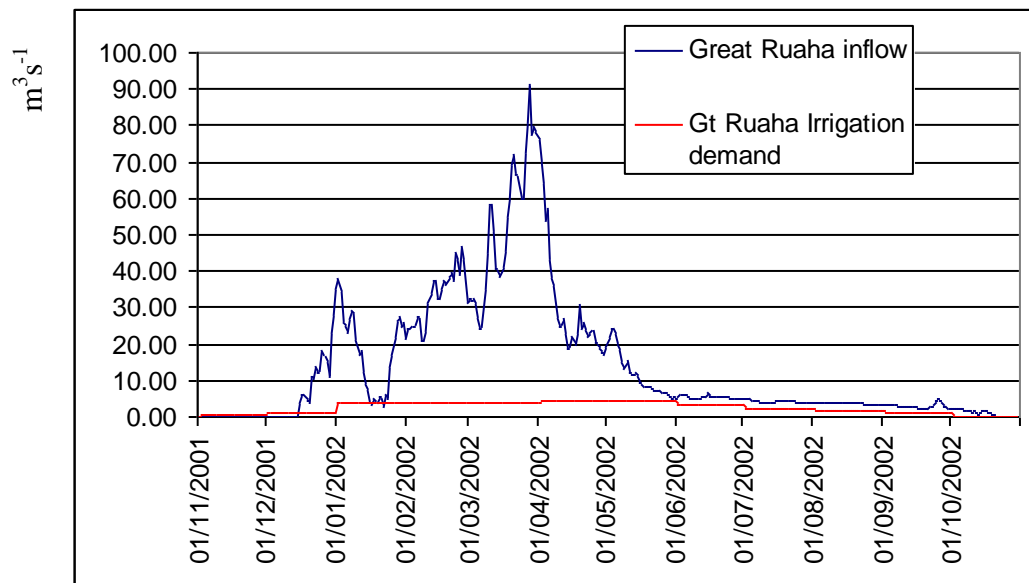




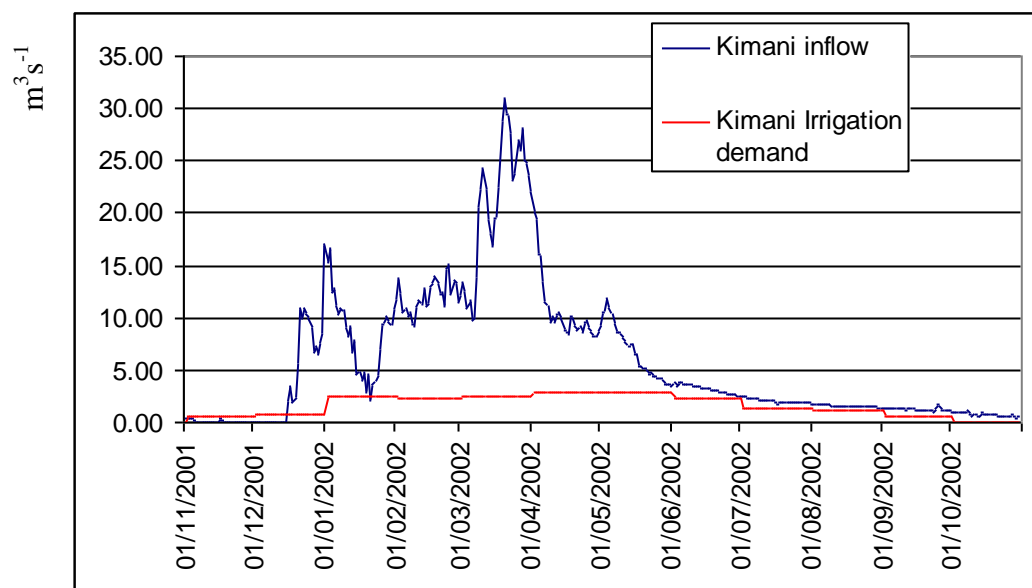
Ndembera SC simulated inflow and outflow. Scenario 2



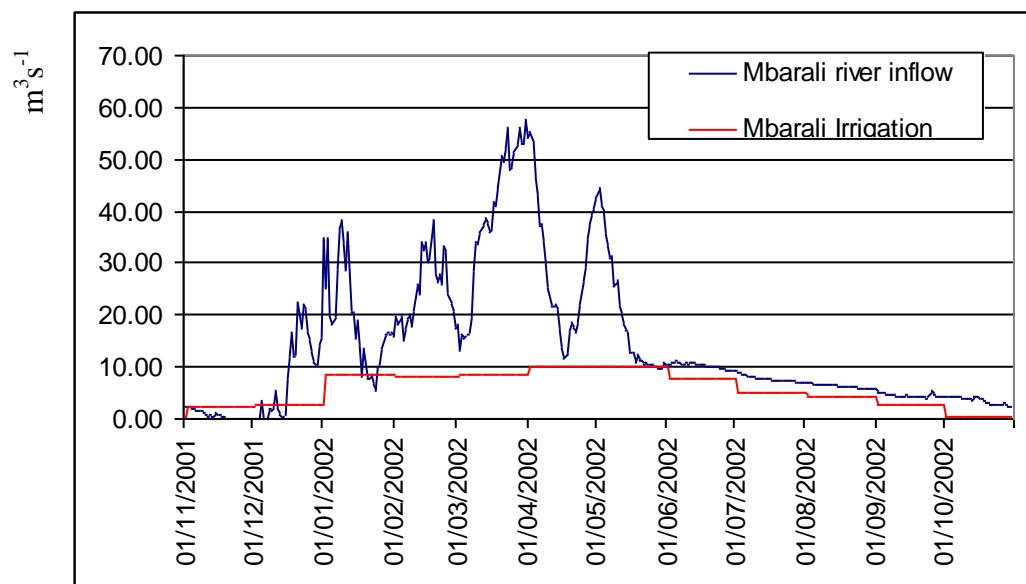
Great Ruaha SC simulated inflow and monthly averages of irrigation demand. Scenario 2.



Kimani SC simulated inflow and monthly averages of irrigation demand. Scenario2.



Mbarali SC simulated inflow and monthly averages of irrigation demand. Scenario 2.

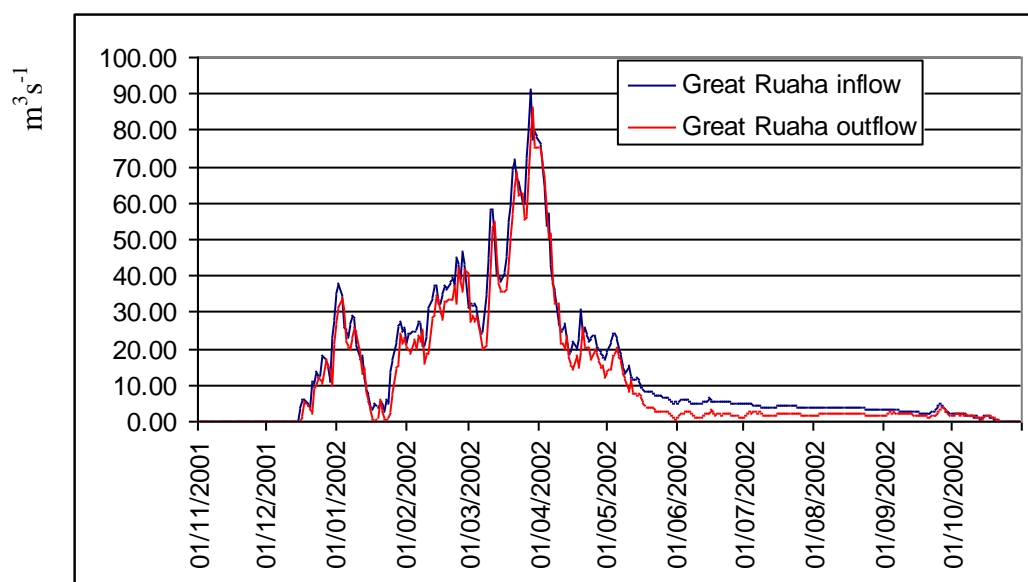


## Irrigation water demand for the current scenario. Scenario 2

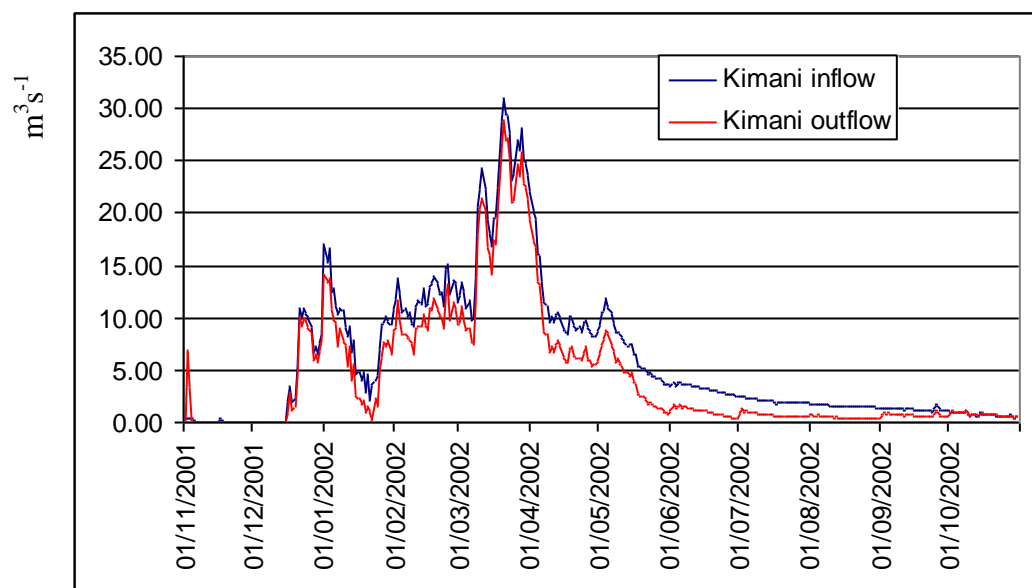
SC	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Itambo	3.20	1.57	5.10	4.13	4.38	5.43	5.87	5.11	4.12	3.88	3.34	1.41
Chimala	0.61	0.37	1.20	1.02	1.08	1.32	1.39	1.18	0.89	0.82	0.65	0.24
Great Ruaha	0.78	1.16	3.76	3.58	3.72	4.35	4.36	3.42	2.10	1.77	0.96	0.05
Kimani	0.52	0.75	2.42	2.31	2.40	2.81	2.81	2.22	1.37	1.16	0.64	0.05
Mlomboji	0.00	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00
Mbarali	2.13	2.66	8.59	8.07	8.39	9.88	9.95	7.90	5.01	4.29	2.52	0.34
Kioga	1.02	1.26	4.08	3.80	3.99	4.70	4.73	3.76	2.39	2.04	1.20	0.17
Ndembera	1.54	1.36	4.41	3.99	4.17	4.98	5.10	4.15	2.84	2.51	1.72	0.46
North Eastern	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kimbi	0.00	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.00
North Western	0.05	0.09	0.28	0.27	0.28	0.33	0.33	0.26	0.15	0.13	0.07	0.00
<b>Total</b>	<b>9.85</b>	<b>9.24</b>	<b>29.88</b>	<b>27.21</b>	<b>28.45</b>	<b>33.84</b>	<b>34.57</b>	<b>28.03</b>	<b>18.89</b>	<b>16.61</b>	<b>11.11</b>	<b>2.73</b>

## Vision scenario Result

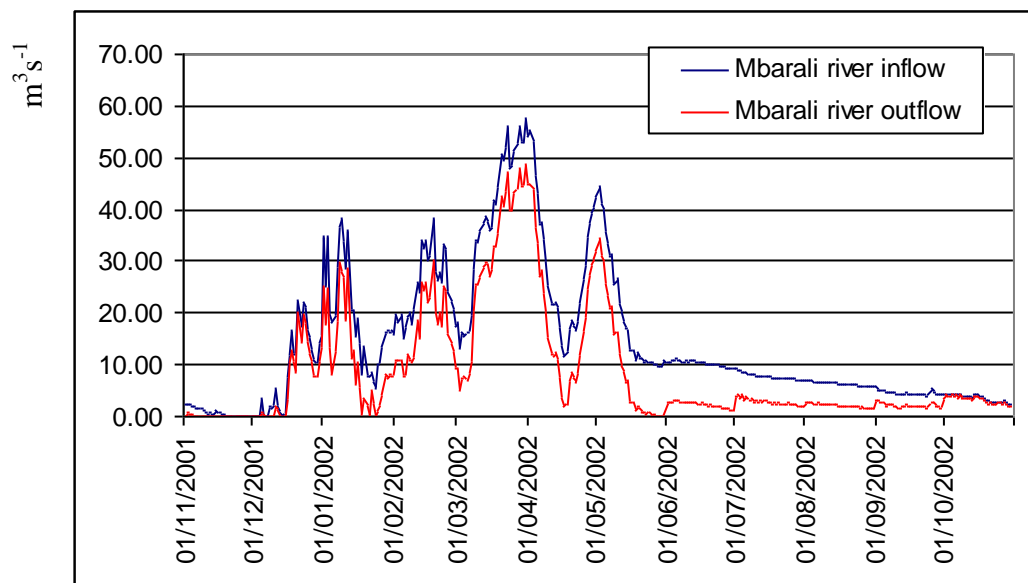
### Great Ruaha SC simulated inflow and outflow. Scenario 3



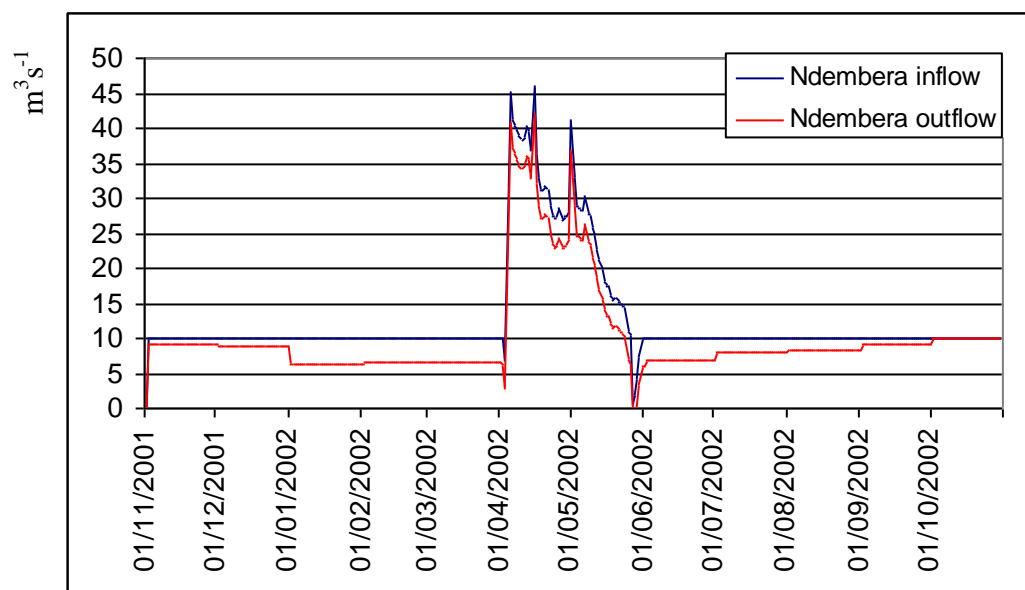
Kimani SC simulated inflow and outflow. Scenario 3



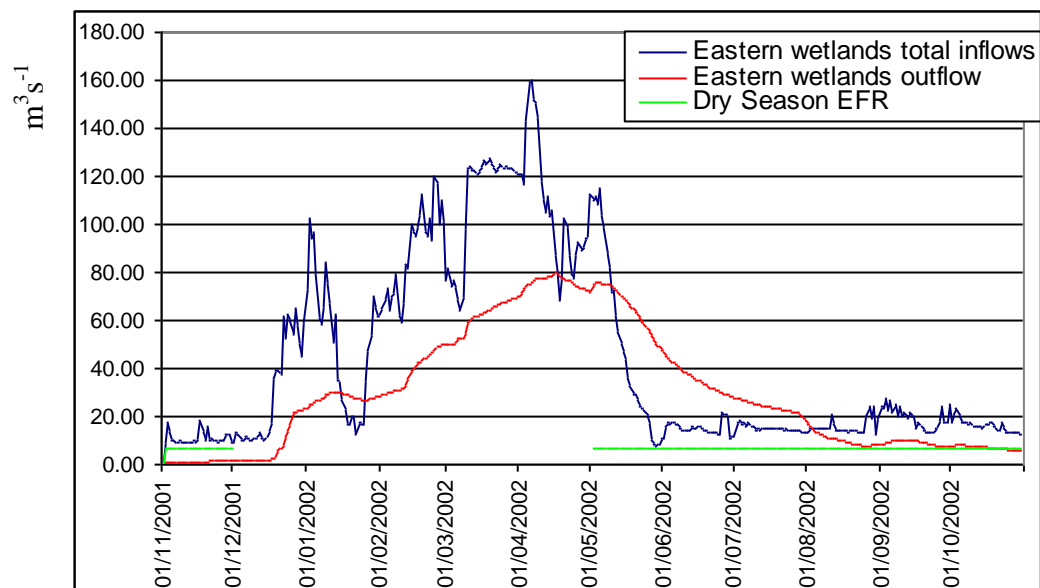
Mbarali SC simulated inflow and outflow. Scenario 3



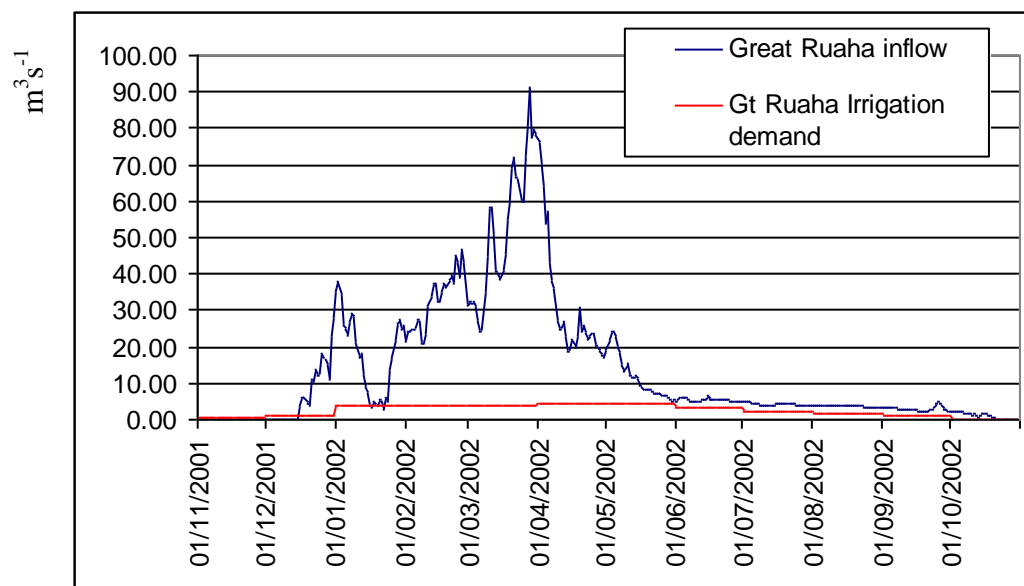
Ndembera SC simulated inflow and outflow. Scenario 3



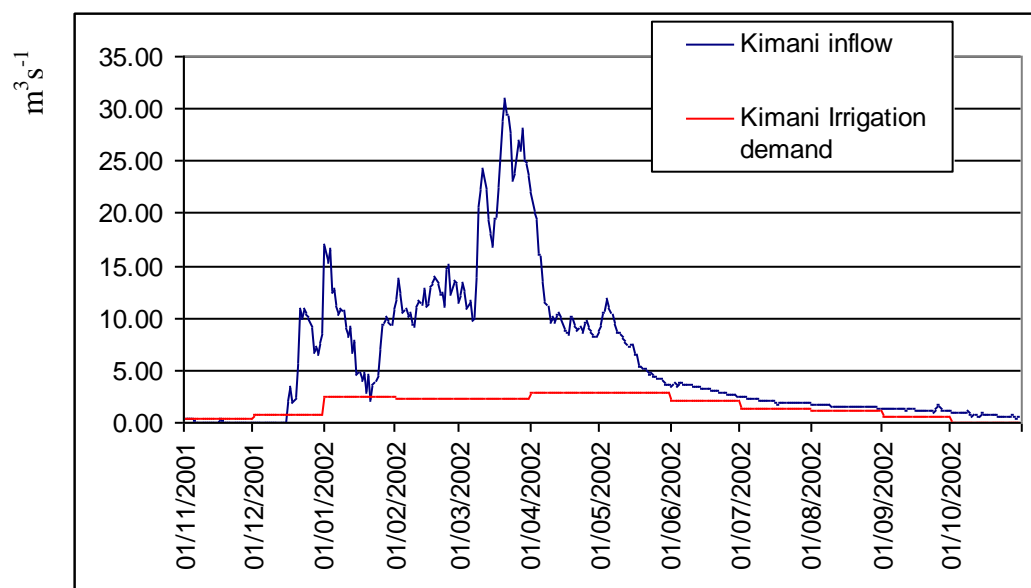
Dry season EFR, Inflows and outflows of the Eastern wetlands. Scenario 3



Great Ruaha SC simulated inflow and monthly averages of irrigation demand. Scenario 3.



Kimani SC simulated inflow and monthly averages of irrigation demand. Scenario 3.



Monthly averages of SC irrigation demand. Scenario 3

SC	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
<b>Itambo</b>	3.20	1.57	5.10	4.13	4.38	5.43	5.87	5.11	4.12	3.88	3.34	1.41
<b>Chimala</b>	0.61	0.37	1.20	1.02	1.08	1.32	1.39	1.18	0.89	0.82	0.65	0.24
<b>Great Ruaha</b>	0.68	1.15	3.72	3.58	3.70	4.33	4.32	3.37	2.03	1.69	0.87	0.00
<b>Kimani</b>	0.44	0.74	2.40	2.30	2.39	2.79	2.78	2.17	1.31	1.09	0.56	0.00
<b>Mlomboji</b>	0.00	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00
<b>Mbarali</b>	1.68	2.60	8.42	8.04	8.35	9.77	9.76	7.66	4.67	3.92	2.08	0.08
<b>Kioga</b>	1.02	1.26	4.08	3.80	3.99	4.70	4.73	3.76	2.39	2.04	1.20	0.17
<b>Ndembera</b>	0.76	1.19	3.55	3.42	3.42	3.99	3.98	3.11	1.93	1.56	0.80	0.00
<b>North Eastern</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<b>Kimbi</b>	0.00	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.00
<b>North Western</b>	0.05	0.09	0.28	0.27	0.28	0.33	0.33	0.26	0.15	0.13	0.07	0.00
<b>Total</b>	8.44	8.99	28.79	26.60	27.63	32.70	33.19	26.65	17.51	15.14	9.58	1.91